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CYCLOPÆDIA:

OR, A NEW

UNIVERSAL DICTIONARY

OF

ARTS and SCIENCES.

Slate

SLATE, *Argillaceous Schistus* and *Argillite* of Kirwan; *Clay-slate*, Jamieson; *Thonschiefer*, Werner; *Schiste Argileux*, Fr.; in *Mineralogy* and *Geology*, one of the great rock-formations composing the crust of the globe, of which roof-slate is a well-known variety. The slaty or schistose structure is common to numerous rocks, which differ from each other, both in their geological position and constituent parts; hence we have a great variety of slate-rocks, amongst rocks which have been denominated primary, transition, and secondary. (See ROCKS.) The term slate appears to have a more appropriate meaning, when restricted to those rocks which, in their composition and structure, are most nearly allied to roof-slate or the clay-slate of Werner.

The most common colours of slate are a yellowish-grey, a greenish-grey, or a dark-blue or purple-grey: some varieties incline to a red, and others to a black-grey. Slate of the most perfect kind has a glistering lustre. It passes by gradation into mica-slate in the rocks called primary; and in rocks considered as secondary, it passes into slate-clay or shale.

The structure of slate-rocks *en masse* is tabular, the small structure lammar, the cleavage of the laminae being parallel with the tables; hence slate has been represented by some geologists as most distinctly stratified; and the slaty cleavage is said to be always parallel with the strata; but this we believe to be a mistake, arising from confounding the divisions or joints of the tabular masses with the inclination of the beds. In the slate-quarries of Westmoreland and Cumberland, we have invariably observed the tables or divisions of the slate rise at a more elevated angle than the bed of which they form a part; and they are sometimes perpendicular, when the true dip of the bed is not more than forty degrees.

The slaty structure of the stone is the result of a process analogous to crystallization, by which the slate is divided into rhomboidal blocks or tables: between the bottom of one block and the top of another, there is frequently a seam of clay, which forms, what the workmen call, the foot of the slate. The slate will divide to this seam in a direction nearly at right angles with it; and sometimes between the upper and the lower block, there will be a thin horizontal stratum of slate occupying the place of the clay. This proves that the slate is not formed by mechanical stratification, and that the elevation of the tabular masses is unconnected with the elevation of the rock itself.

Slate-rocks vary in hardness, but they yield to the knife. They consist of an intimate intermixture, in various proportions, of siliceous earth, alumine, and iron; and sometimes

contain a portion of lime, magnesia, manganese, and bitumen. Slate forms entire mountains, and mountain chains, and sometimes distinct beds, alternating with other rocks. It most frequently rests upon granite, gneiss, or mica-slate.

Slate-rocks are frequently intersected by veins of quartz, and by metallic veins of lead, cobalt, and silver: it also contains beds of copper pyrites, red copper-ore, copper-green, malachite, iron pyrites, magnetic pyrites, glance cobalt, grey cobalt-ore, arsenical pyrites, blende and galena. The tin-veins in Cornwall sometimes pass through the killas, which is a variety of slate-rock.

Various rocks frequently occur imbedded in slate, particularly whet-slate, or hone, chlorite-slate, talcous-slate, drawing-slate, and alum-slate. Beds of flinty slate occur in this rock, and alternate with as well as graduate into it. Flinty slate appears to be slate in which a large proportion of siliceous earth is combined, until it approaches nearly to the nature of chert or flint. Organic remains are occasionally found in slate, on which account it is not considered by many geologists as a primary rock, if indeed there be any to which that term is appropriate. The slate which contains organic remains has been called by the Germans *the newer clay-slate*, and *transition slate*; but remains of vegetables have been discovered in the slate of the Higher Alps in the vicinity of Mont Blanc, which may be supposed to have a better claim to the rank of primary than any other slate-rocks in Europe.

In a very large proportion of slate-rocks, the basis of the slate is intermixed with particles or fragments of other rocks; and when these are sufficiently large to be discerned without a lens, this kind of rock has received from the Germans the name of *grauwacke slate*. It is generally incumbent on the rocks denominated primary, and is supposed to be of more recent origin than the finer slate; but late observations have shewn that grauwacke is sometimes covered with granite and mica-slate. The killas of Cornwall appears, in many situations, to approach the nature of mica-slate, having a shining lustre, and a light grey colour, as if composed of an intimate intermixture of clay-slate with mica-slate. In Cornwall and Devonshire it occupies, in general, the same relative position with granite, in which mica-slate frequently occurs in other districts resting immediately upon it. The metallic veins which intersect these rocks are principally filled with ores of tin and copper, imbedded in a matrix of quartz; but it is observed, that the contents of the vein frequently vary as it passes through different rocks: if it contain tin-ore in the granite, it will change to copper-ores in the killas; and if tin be most

abundant in the killas, the vein will change its contents as it passes into the granite. Veins of granite are also observed to shoot up into the killas, which is a proof that this kind of slate-rock is at least as ancient as the granite. This fact has given rise to some controversy among geologists, the disciples of Werner contending that the granite in the slate or killas was not in veins, but formed ridges or inequalities rising above the surface, which had been inclosed by subsequent depositions of the slate. For this explanation there can be no better reason given than its convenience in suiting a particular hypothesis respecting the formation of these rocks. Among other facts, which might be cited to prove that the granite veins penetrate the slate, there is one described in the "Annals of Philosophy," May 1814, which appears decisive. It occurs in Toulshole, in Cornwall. "The slate or killas is of a greyish dark colour, rather hard, but breaks into large fragments in the direction of the strata. The granite is of a fine grain, and the felspar is of a light flesh-colour, and contains but a small portion of mica. At the junction, numerous veins of granite may be traced from the rock of granite into the slate. Some of these veins may be observed upwards of fifty yards, till they are lost in the sea; and in point of size, vary from a foot and a half to less than an inch. It may deserve notice, that as the felspar is of a flesh-red colour, it is impossible for any observer to consider them as quartz veins. One of these large veins is dislocated, and heaved several yards by a cross course. Another of these veins of granite, after proceeding vertically some distance, suddenly forms an angle, and continues in a direction nearly horizontal for several feet, with schistus, or slate, both above and below it. This appearance most completely destroys one of the theories suggested for the explanation of similar veins at St. Michael's Mount; viz. that a ridge of projecting granite had been left, and slate deposited afterwards on its sides." It is, indeed, quite impossible to conceive that a narrow vein of granite should shoot up into empty space for a considerable distance, and then assume a zig-zag direction, unsupported by any solid substance on the sides. The slate-rock must have existed when the vein was formed, and from its resistance have given it the form above described. Slate is one of the most abundant rocks in alpine districts, though that variety which splits into thin durable laminæ, forming good roof-slate, is far from being so common. The localities of common slate are so numerous in mountainous districts, that it were useless to point them out. Roof-slate, the *schiste ardoise* of the French, is found on the western side of our island in the counties of Cornwall and Devon, in various parts of North Wales and Anglesea, on the north-west parts of Yorkshire, near Ingleton, and in Swaledale, also in the counties of Cumberland and Westmorland. It occurs in a low range of mountains at Chamwood forest, in Leicestershire, near the centre of England. Several geologists have stated that slate is found in Derbyshire, which is a mistake, as no rock similar to clay-slate or roof-slate occurs in that county. The inhabitants of that part of England make use of a micaceous sand-stone for roofing, which they denominate slate. This stone is found in strata among the other strata accompanying coal. Of the quality of the different kinds of English roof-slate, we shall offer some observations at the conclusion of this article. Slate abounds in various parts of Scotland, and in the county of Wicklow, and other mountainous parts of Ireland. France possesses many valuable beds of roof-slate, near Laferrière in Normandy, and in the neighbourhood of Angers. The last is the most important, as furnishing

slate of the most perfect quality, and its extent and prodigious thickness make it regarded as inexhaustible. It is further remarkable on account of the very singular and interesting organic remains that occur between some of the laminæ of slate. It is, perhaps, one of the most valuable repositories of slate at present known.

This bed extends for a space of two leagues, passing under the town of Angers, which is built, as well as covered, with the slate; those blocks being employed in masonry which are the least divisible. The quarries which are actually explored, are all in the same line from west to east, as well as the ancient pits, the bed of the best roof-slate rising to the surface in this direction. Immediately under the vegetable earth is found a brittle kind of slate, which, for four or five feet deep, splits into rhomboidal fragments.

A little lower is what is called the building-stone, which is a firm slate, but scarcely divisible. This is employed in the construction of houses, after it has been sufficiently hardened by exposure to the air. At fourteen or fifteen feet from the surface is found the good slate, which has been quarried to the perpendicular depth of about three hundred feet; the remaining thickness being unknown.

As to the interior structure of this great mass of slate, it is divided by many veins or seams of calcareous spar and quartz, about two feet thick, by fifteen or sixteen in height: these veins are parallel, and proceed regularly from west to east, in a position rising seventy degrees to the south; they are intersected by other veins at intervals of a similar kind, but whose rise is seventy degrees north; so that when they meet the former, they either form rhombs, or half rhombs, which have been compared to the letter V, some being upright, and others reversed.

All the layers, or laminæ, of the slate, have a direction similar to those of the veins of quartz, which rise south seventy degrees; and when intersected by veins that have an opposite inclination, the direction of the slaty laminæ is not changed. The whole mass is thus divided into immense rhomboids, composed of plates all parallel among themselves, and with two of the faces of the rhomboid.

The slate of Angers is extracted in blocks of a fixed size, which are divided into leaves for roofing-slate. It is betwixt these leaves that there are frequently found vestiges of marine animals, and particularly pyritous impressions of *pous de mer* (the sea-louse, a small univalve shell), also of small cheviettes (shrimps or prawns), and a species of crab, of which the body is about a foot in breadth, and fourteen or fifteen inches in length, the tail having nine or ten rings. The shrimps are sometimes so numerous, that forty have been counted on a slate of a foot square.

None of the above animals resemble any known existing species. But the most remarkable circumstance in these impressions, particularly in the large crabs, is, that though there be no sign of the body having been crushed, yet it can scarcely be said to have any thickness whatever. They rather resemble engravings than figures in relief, the convexity of these crabs above a thin leaf of slate not rising more than the fourth, and sometimes not more than the tenth part of a line; nor is it perceivable that the body of these crabs penetrates into the leaves of slate. What adds to the surprise, is the nearly vertical position in which these impressions are found in the mine.

A series of these leaves of slate may be compared to a set of books placed upon shelves; and the impressions of crabs, and other marine animals, to engraved plates in the volumes: they do not, in fact, occupy more thickness. It is equally difficult to conceive how the bodies of these animals, though perfectly defined, could be reduced to a simple surface, with-

out thickness. These slates also present beautiful dendritic pyrites, more than a foot in extent. The pyrites are sometimes in small grains, disseminated, like dust, upon the surface of the slates, where may also be observed many little stars of selenite.

When the blocks of slate have been drawn from the quarry, if they are left exposed to the sun, or the open air, for some days, they lose what is called the *quarry-water*, and then become hard and untractable, and can only be employed as building stone. Frost produces a singular effect on these blocks: while frozen they may be broken with more ease than before; but if thawed rather quickly, they are no longer divisible: yet this quality may be restored by exposing them once more to the frost; but if the operation be often repeated, it becomes impossible to reduce them to leaves.

Some smaller beds of slate are worked on the northern declivities of the Pyrenées; but we have no account of any slate-quarries on the southern side, or in any part of Spain: yet it can scarcely be doubted that this rock exists in some of the mountainous parts of that kingdom.

Only one quarry of slate is said to be opened in Italy; it is at Lavagna, in the state of Genoa, and furnishes slate of an excellent quality, and so impervious, that it serves to line the cisterns in which olive oil is preserved. The canton of Glaris, in Switzerland, is the only one in which roof-slate is procured. Roof-slate occurs in Saxony, and in various mountainous districts in the north of Europe; it is found also on the continent of North America; and as it is only a modification of clay-slate, which is an abundant rock, it is probable that its localities are much more numerous than are at present known in alpine districts in every part of the globe.

As this substance forms the most light, elegant, and durable covering for houses, and is, of course, of considerable value; it is rather surprising that so much indifference prevails respecting the search for it, in those districts where common slate, or *clay-slate*, abounds. We believe all the roof-slate quarries at present worked are those which accident has discovered. This neglect is the more remarkable, when we consider the great expence frequently incurred in searching for coal, a substance of much less value in proportion to the weight.

All the best beds of roof-slate with which we are acquainted, improve as they sink deeper into the earth; and few, if any, are of a good quality near the surface, or are indeed suitable for the purpose of roofing. There cannot be a doubt that many beds of slate, which appear shattered and unfit for architectural use, would be found of a good quality a few yards under the surface; for the best slate, in many quarries, loses its property of splitting into thin laminæ by exposure to the air. Notwithstanding the value of slate, few quarries are worked to a very great depth, or have subterranean galleries, like mines. The quarry or slate-mine at Rimsagne, four leagues to the west of Charleville, on the Meuse, in France, is an exception. The mouth of the mine is near the summit of a hill: the bed inclines forty degrees to the horizon: it is about sixty feet in thickness, but its extent and depth are unknown. It has been pursued, by a principal gallery, to the depth of 400 feet; and they have driven many lateral galleries, which extend about 200 feet on the side of the main gallery, where 26 ladders are placed in succession, for the passage of the workmen and the carriage of the slate. In this bed, which is 60 feet in thickness, there are only forty feet of good slate, the other being mixed with quartz. They cut the slate into blocks of about 200lbs., which they call *faix*: every workman, in

his turn, carries them on his back to the very mouth of the pit, mounting the 26 ladders, or a part of them, according to the depth of the bed where he is working. When brought to day, these blocks are first split into thick tables, which are called *repartons*. The workman holds the block between his legs, puts a chissel on the side, and divides it with a blow of a mallet. The *repartons* are divided in a similar manner into roof-slates. These operations must be performed soon after the blocks are drawn from the quarry; for if the stone has time to dry, it would no longer be possible to split it. Some of the slate-galleries pass under the river Meuse.

There are few places in Great Britain where slate is worked as a mine under ground; most of the quarries are open to the day; and the covering of other rocks, or of coarse slate, which requires removing, greatly increases the expence. There is one slate-quarry worked as a mine by penetrating the interior of the mountain at Place-Fell, on the head of the lake of Ullswater, in Cumberland. Slate is also worked under ground on the western side of Yorkshire, adjoining Westmoreland. In many other situations it is probable that slate might be worked to advantage, in subterranean galleries, similar to those described in the quarries at Charleville; for as this mineral is generally of a better quality at a considerable depth, the expence of procuring it by mining would be much less than that of removing the load of upper rocks, and working it in open quarries, as at present; at least the most valuable slate might be pursued to a far greater depth than is practicable in the common method in open quarries.

Slate, to be of a good quality for roofing, should have the property of splitting into thin even laminæ: it should resist the absorption of water; to prove which, it should be kept some time immersed in water, being weighed before and after the immersion, wiping the surface dry; it is obvious, that the slate which gains the least weight by this process is the least absorbent. It should resist the process of natural decomposition by air and moisture: this depends on its chemical composition and compactness, and is shewn by its resisting the process of vegetation. That slate which is the most liable to decay, will be the soonest covered with lichens and mosses. The slate from Chamwood forest, in Leicestershire, resembles, in colour and appearance, the Westmoreland slate, but it will not split so thin, nor would this be desirable, for the vegetation which takes place upon it requires the roofs to be frequently scraped; this carries away a portion of the surface: a second growth of mosses produces a further wearing of the slate: hence a slate of a certain thickness from this part of England is not so durable as that from North Wales, Cornwall, or Westmoreland. This decay is probably owing to the greater quantity of alumine in its composition; it does not contain pyrites, nor have any organic remains been discovered in it.

Few slate-rocks have been accurately analysed; a reddish-purple slate from North Wales contained, according to Kirwan, .38 silice, .26 alumine, .8 magnesia, .4 lime, and .14 parts iron; but as there is in this analysis a loss of 10 per cent., it cannot be considered as very accurate. As the hardness of slate arises principally from the silice it contains, which is of all the earths the least favourable to vegetation, those slates which are the hardest when first taken from the quarry, and which have the least specific gravity, are to be preferred; for the increase of weight in slates is owing to the presence of iron, either in pyrites, or a slate of oxyd. To the presence of iron, many kinds of stone and slate also owe their tendency to decomposition. The pyrites being decomposed by moisture, and the iron admitting

a still higher degree of oxygenation, the surface of the stone swells and peels off, or falls into an ochrey powder.

According to Dr. Watson, (bishop of Landaff,) the specific gravity of the Westmoreland slate varies in different quarries, from 2707 to 2732 ounces the cubic foot. The effect of frost is very sensible on tiled houses, but is scarcely felt on slated houses; for good slate imbibes very little water. According to an experiment made by Dr. Watson on Westmoreland slate, compared with tile, in which two pieces of each, about 30 inches square, were immersed in water 10 minutes, and then taken out and weighed as soon as they ceased to drop; the tile had imbibed about $\frac{1}{4}$ th of its weight of water, and the slate had not absorbed the $\frac{1}{30}$ th part of its weight: indeed the wetting of the slate was merely superficial. When placed before the fire, in a quarter of an hour the slate was of the same weight as it had been before it was put into the water; but the tile had only lost about 12 grains of its moisture, which was as near as could be expected to the quantity which had been spread over its surface; for it was the amount gained by the slate, the surface of which was equal to that of the tile. The tile was left to dry six days, in a room heated to sixty degrees, but did not lose all the water it had imbibed till the end of that time.

The slate in Westmoreland is blatted from the quarry in large masses, and split with proper tools by the workmen. Though the specific gravity of Westmoreland slate from different quarries is nearly the same, yet all the sorts are not capable of being split into an equal degree of thinness. Here also the quality varies with the depth of the quarry, that being the best which is raised from the greatest depth.

The grey-blue slate from Donyball, in Cornwall, weighs only 2512 ounces to the cubic foot, which is considerably lighter than that of Westmoreland. This slate is generally preferred to any other for its lightness, and enduring the weather; but Dr. Watson is of opinion, that in durability it does not excel that of Westmoreland. The Donyball slate is split into laminæ about one-eighth of an inch thick when it is applied to the covering of a roof; it then weighs rather more than 26 ounces to the square foot. The pale blue slate from Ambleside, in Westmoreland, weighs about two ounces more in the square foot than the former. In many instances, we believe slate of a thinner kind is used in several modern buildings to save the expence of timber in the roof, where cheapness rather than durability is a principal object with the architect. According to an estimate of Dr. Watson, the relative weights of a covering of the following different materials, for forty-two square yards of roof, are as under:

	Cwt.
Copper	4
Fine slate	26
Lead	27
Coarse slate	36
Tile	54

A ton of fine slate will cover a larger surface than a ton of lead; and where there is water-carriage, does not cost one-fourth of the price. Slate might, therefore, be used generally instead of lead, with great advantage. Watson's Chemical Essays, vol. iv.

The most extensive slate-quarries in Great Britain are the property of lord Penryn, near Bangor, in Caernarvonshire. There is a rail-road formed from the quarries to the sea for the conveyance of the slate, which is of an excellent quality, and is sent to various parts of the world. The most remarkable situation where slate is procured in Cum-

berland, or perhaps in Great Britain, is Hourlston cragg, a lofty mountain near the lake of Buttermere, about 2000 feet above the level of the lake, and nearly perpendicular. On account of the difficulty of access, the workmen take their provisions for the week, and sleep in temporary huts on the summit. During the winter months they are generally involved in clouds, and not unfrequently blocked up by the snow. The slate is conveyed down a zigzag path cut in the rock on sledges, one man attending to prevent the acceleration of the descent. When the slate is emptied at the bottom, the sledge is carried back on his shoulders to the summit.

There are considerable slate-quarries near Ulverstone, in Lancashire. A coarse slate is got near Ingleton, in Yorkshire, and also in the vicinity of Settle in that county. The Ingleton slate frequently contains cubical pyrites, and is sometimes covered with dendritical pyrites.

Alum-slate, *ampellite* of Haüy, is sometimes imbedded in clay-slate, but more frequently in stratified secondary rocks, and is not essentially different from some of the coal-shales. (See ALUM.) The alum-slate, or alum-shale of Whitby, is of vast and unknown thickness, forming the base of the Cleveland Hills in the North Riding of Yorkshire, extending about thirty miles east and west from Robinhood's bay, to Gainsborough, Stokesly, and Osmotherly. On the south side of the Cleveland Hills the alum-slate is principally covered by sand-stone and marl. On the north-east, the alum-rock extends along the coast, about thirty miles from Robinhood's bay to Huntcliff. The height of the alum-cliffs, which are perpendicular from the sea, varies from 100 to 140 yards. Whitby abbey stands near an awful precipice of alum-slate or rock, which is undermined by every returning tide. At low water the alum-rock may be seen extending far to the east, forming a flat pavement, on which the observer may walk secure, treading at almost every step on the organic remains of the inhabitants of a former world, which are abundantly disseminated through the whole mass beneath, and projecting from the sides of the black and frowning cliffs above. The alum-slate has been perforated near the sea to the depth of 130 yards, without discovering the subjacent rock, to which we may add the height of the cliffs above, which will make a total thickness exceeding 220 yards. The upper parts of the bed are found more productive of alum than the lower. From the quantity of pyrites contained in this rock, it sometimes takes fire spontaneously, when a heap of it which has fallen from the cliffs becomes moistened with sea-water.

The animal remains are scattered through every part of the rock. They consist principally of numerous ammonites, nautilites, belemnites, fossil vertebræ (supposed to belong to the shark), with bivalve shells, fossil wood, and jet. Mr. Bakewell considers the alum-shale or slate, and the strata which cover it, as a peculiar local formation subjacent to the roe-stone, but above the coal-formation of Yorkshire or Durham. The alum-slate is in fact a thin bed of indurated pyritous slate-clay, differing little, except in geological position and its organic remains, from some of the coal-shales.

The alum-slate of Whitby has a very dark grey colour, a slaty structure, and rather a silky lustre; it splits, by exposure to the atmosphere, into very thin laminæ; it varies in hardness, but is all softer than roof-slate. The particular advantage which the country near Whitby possesses for the manufacture of alum, is derived from the alum-slate rising in precipitous cliffs, which afford facilities for working and burning the stone. Though many of the coal-shales might yield an equal quantity of alum, the difficulty of raising

them to the surface would in most situations be too great to repay the expence. The alum-slate is piled in vast heaps and set fire to; a slow combustion is continued for several months, by the inflammable matter combined with the stone. The saline contents are extracted by solution, a small quantity of potash is added, and the alum is crystallized by evaporation. (Bakewell's Introduction to Geology.) From the alum-rock of Yorkshire, nearly all the alum of commerce in England is produced.

According to the analysis of Klaproth, alum-slate contains

Sulphur	-	-	-	-	0.28
Carbon	-	-	-	-	1.96
Alumine	-	-	-	-	1.60
Silex	-	-	-	-	4.00
Black oxyd of iron	-	-	-	-	64
Sulphate of iron, lime, and potash, each	-	-	-	-	15
Water	-	-	-	-	70

M. Klaproth remarks, that the sulphur in the alum-slate which he analysed was not united to the iron but to the carbon, in a manner at present unknown. In the alum-slate of Whitby, we believe the sulphur is combined both with the iron and carbon.

Drawing-slate frequently accompanies alum-slate; it is much softer than common slate, and contains, like alum-slate, a considerable portion of carbon: its colour is a greyish-black: it is known by the property which it possesses of leaving a dark line when rubbed on paper. It is soft, and sometimes rather unctuous: some varieties have a small degree of lustre. The fracture, in small fragments, is scarcely flaty, and sometimes approaches the conchoidal. Drawing-slate is easily cut with the knife. Under the blowpipe it turns white or yellow. It sometimes effloresces like alum-slate. According to Wiegleb, it contains

Silex	-	-	-	64
Alumine	-	-	-	21.25
Carbon	-	-	-	11
Oxyd of iron	-	-	-	2.75
Water	-	-	-	7.50

Drawing-slate is employed by masons, carpenters, &c. to mark with. When fine and pure, it is used by artists for designs. In France it is called *ierre d'Italie*, in England, *French chalk*. It is found in France, near Séer, in the department of l'Orne, and in the environs of Cherbourg. It is found also in Spain and Italy.

Whet-slate, or hone, the *novaculite* of Kirwan, occurs imbedded in clay-slate: its most common colour is greenish-grey, inclining to yellow: it is much harder than common slate: its texture is fine-grained, nearly compact, and the fracture of the small pieces splintery or conchoidal, resembling flinty slate. Its specific gravity is about 2.72. Whet-slate is translucent on the edges; it does not effervesce with acids, and it melts into a brown enamel under the blowpipe. From its green colour, and rather greasy feel, it may be considered as intermediate between hard talcous-slate and clay-slate. Though it yields to the point of a knife, or even of a copper tool, it acts upon the flattened or round surfaces of metals, and is used for sharpening and polishing the finer kinds of cutlery. It is of considerable value on account of this property, and was first brought from the Levant. We have no whet-slate of a fine quality in England. An inferior kind is procured from Chamwood forest, in Leicestershire. It exists of a finer quality in the promontory of Howth, near Dublin. The common whet-slate of commerce is procured from Saxony.

SLATE-Spar, *Schiefer-spath*, Werner, occurs in lime-stone beds, in mountains called primitive. Its colour is milk-white, or greenish and reddish-white, its lustre shining and pearly. Slate-spar is translucent and soft, its structure coarsely lamellar, passing into flaty, and sometimes curved or undulating: it is infusible, and effervesces with violence in acids.

SLATE, in *Rural Economy*, a well-known, neat, convenient, and durable material, for the covering of the roofs of buildings. There are great varieties of this substance; and it likewise differs very greatly in its qualities and colours. In some places it is found in thick laminæ, or flakes; while in others it is thin and light. The colours are white, brown, and blue.

It is so durable, in some cases, as to have been known to continue sound and good for centuries. However, unless it should be brought from a quarry of well reputed goodness, it is necessary to try its properties, which may be done by striking the slate sharply against a large stone, and if it produce a complete sound, it is a mark of goodness; but if in hewing it does not shatter before the edge of the *set*, or instrument commonly used for that purpose, the criterion is decisive. The goodness of slate may be farther estimated by its colour: the deep black-blue is apt to imbibe moisture, but the lighter blue is always the least penetrable: the touch also may be in some degree a guide, for a good firm stone feels somewhat hard and rough, whereas an open slate feels very smooth, and as it were greasy. And another method of trying the goodness of slate, is to place the slate-stone lengthwise, and perpendicularly in a tub of water, about half a foot deep, care being taken that the upper or unimmerged part of the slate be not accidentally wetted by the hand, or otherwise; let it remain in this slate twenty-four hours; if good and firm stone, it will not draw water more than half an inch above the surface of the water, and that perhaps at the edges only, those parts having been a little loosened in the hewing; but a spongy defective stone will draw water to the very top. There is still another mode, held to be infallible. First, weigh two or three of the most suspected slates, noting the weight; then immerge them in a vessel of water twelve hours; take them out, and wipe them as clean as possible with a linen cloth; and if they weigh more than at first, it denotes that quality of slate which imbibes water: a drachm is allowable in a dozen pounds, and no more.

It may be noticed, that in laying of this material, a bushel and a half of lime, and three bushels of fresh-water sand, will be sufficient for a square of work; but if it be pin plastered, it will take above as much more: but good slate, well laid and plastered to the pin, will lie an hundred years; and on good timber a much longer time. It has been common to lay the slates dry, or on moss only, but they are much better when laid with plaster. When they are to be plastered to the pin, then about the first quantity of lime and sand will be sufficient for the purpose, when well mixed and blended together, by properly working them.

Slates differ very much in thickness as well as colour, which suits them for different situations and purposes. A great deal of good slate of various kinds is raised in different parts of Wales, and much excellent blue and other coloured sorts is procured from the northern parts of Lancashire, and other neighbouring places, as well as from different other counties throughout the kingdom. In some parts the slate is distributed into three kinds, as the best, the middling, and the waste or common sort. See QUARRY.

SLATE-*Axe*, provincially a mattock with a short axe-end, used in slating, &c.

Slich

SLICH, in *Metallurgy*, the ore of any metal, particularly of gold, when it has been pounded, and prepared for farther working.

The manner of preparing the slich at Cremnitz, in Hungary, is this: they lay a foundation of wood three yards deep, upon this they place the ore, and over this there are four-and-twenty beams, armed at their bottoms with iron; these, by a continual motion, beat and grind the ore, till they reduce it to powder: during all this operation, the ore is covered with water. There are four wheels used to move these beams, each wheel moving six; and the water, as it runs off, carrying some of the metalline particles with it, is received into several basons, one placed behind another; and finally, after having passed through them all, and deposited some sediment in each, it is let off into a very large pit, of almost half an acre of ground; in this it is suffered to stand so long, as to deposit all its sediment, of whatever kind, and after this it is let out. This work is carried on day and night, and the ore taken away, and replaced by more, as often as occasion requires. That ore which lies next

the beams, where it was pounded, is always the cleanest or richest.

When the slich is washed as much as they can, a hundred weight of it usually contains about an ounce, or perhaps but half an ounce of metal; which is not all gold, for there is always a mixture of gold and silver, but the gold is in the largest quantity, and usually is two-thirds of the mixture: they then put the slich into a furnace with some lime-stone, and slaken, or the scoria of former meltings, and run them together. The first melting produces a substance, called *lech*; this lech they burn with charcoal, to make it lighter, to open its body, and render it porous, after which it is called *roß*; to this roß they add sand in such quantity as they find necessary, and then melt it over again.

They have at Cremnitz many other ways of reducing gold out of its ore, but particularly one, in which they employ no lead during the whole operation; whereas, in general, lead is always necessary, after the before-mentioned processes. See GOLD.

Smeaton

SMEATON, JOHN, an eminent civil engineer, was born on the 28th of May, 1724, at Austhorpe, near Leeds. The strength of his understanding, and the originality of his genius, appeared at an early age; his playthings were not the playthings of children, but the tools which men employ; and when he was a mere child, he appeared to take greater pleasure in seeing the operations of workmen, and asking them questions, than in any thing else. Before he was six years old, he was once discovered at the top of his father's barn, fixing up what he called a wind-mill of his own construction; and at another time, while he was about the same age, he attended some men fixing a pump, and observing them cut off a piece of the bored part, he procured it, and actually made a pump, with which he raised water. When he was under fifteen years of age, he made an engine for turning, and worked several things in ivory and wood, which he presented to his friends. He made all his own tools for working in wood and metals, and he constructed a lathe, by which he cut a perpetual screw in brass, a thing but little known, and which was the invention of Mr. Henry Hindley of York, with whom Mr. Smeaton became acquainted, and indeed extremely intimate. Mr. Smeaton, by the time that he was eighteen years of age, acquired, by the strength of his genius and indefatigable industry, an extensive set of tools, and the art of working in most mechanical trades, without the assistance of a master. A part of every day was usually occupied in forming some ingenious piece of mechanism. His father was an attorney, and being desirous to bring up his son to the same profession, he brought him up to London with him in 1742, and attended the courts in Westminster-Hall; but after some time,

finding that the law was not suited to his disposition, he wrote a strong memorial to his father on the subject, who immediately desired the young man to follow the bent of his inclination. In 1751 he began a course of experiments to try a machine of his own invention to measure a ship's way at sea, and also made two voyages, in company with Dr. Knight, to try the effect of it, and also for the purpose of making experiments on a compass of his own construction, which was rendered magnetical by Dr. Knight's artificial magnets. In 1753 he was elected a fellow of the Royal Society; and the number of papers which he published in their Transactions, will shew how highly he deserved the honour of being enrolled a member of that useful and important body. In 1759 he received from the council of the Royal Society, by an unanimous vote, their gold medal for his paper, entitled "An experimental Inquiry concerning the natural Powers of Water and Wind to turn Mills and other Machines, depending on a circular Motion." The paper was the result of experiments made on working models in the years 1752 and 1753, though not communicated to the society till 1759; and in the interval he had opportunities of carrying into effect several of his inventions and theories, which rendered his paper of much more real value to the society and the public at large. In 1755, the EDDYSTONE *Light-house* was burnt down (see the article), and Mr. Smeaton being recommended to the proprietors of that building as an engineer in every way calculated to rebuild it, he undertook the work, which was completed in 1759, much to the satisfaction of the parties concerned. Still he was not fully employed as a civil engineer, for in the

year 1764, while he was in Yorkshire, he offered himself as a candidate for the office of receiver to the Derwent water estate; and in the course of the year he obtained the appointment in a manner most flattering to himself, inasmuch as his own merit carried the point in opposition to two other candidates who were strongly recommended and powerfully supported. He was very happy in this appointment, particularly in the assistance which he received from Mr. Walton, the other receiver, who took upon himself the management of the accounts, leaving Mr. Smeaton leisure and opportunity to exert his abilities on public works. In the year 1773, he had so much business as a civil engineer, that he wished to resign this appointment; but his friends prevailed on him to continue in office two years longer. After this, Mr. Smeaton was employed on many works of great public utility. He made the river Calder navigable, a work that required talents of the very first order, owing to the impetuous floods in that river; he planned and attended to the execution of the great canal in Scotland, for conveying the trade of the country either to the Atlantic or German ocean; and as a proof of the disinterestedness of his habits, having brought it to the place originally intended, he declined a handsome yearly salary, in order that he might attend to other business. On the opening of the great arch at London-bridge, the excavation around and under the starlings was so considerable, that the bridge was thought to be in great danger of falling. Mr. Smeaton was then in Yorkshire, and was sent for express, and he arrived without any delay. "I think," says his biographer, "that it was on a Saturday morning when the apprehension of the bridge was so general, that few persons would venture to pass over or under it. Mr. Smeaton applied himself immediately to examine it, and to sound about the starlings as minutely as possible, and the committee being called together, adopted his advice, which was to repurchase the stones that had been taken from the middle pier, then lying in Moorfields, and to throw them into the river to guard the starlings. In this way Mr. Smeaton probably saved London-bridge from falling, and secured it till more effectual methods could be adopted."

Mr. Smeaton was appointed engineer to Ramsgate harbour, and brought it into a state of great utility by various operations, of which he published an account in 1791. The variety of mills which Mr. Smeaton constructed, shews the great uses which he made of his experiments already referred to; for it was a rule with him, from which he never willingly deviated, not to trust to theory in any case, where he could have an opportunity to investigate a subject by real trial. He built a steam-engine at Aulthorpe, and made a vast number of experiments with it to ascertain the power of Newcomen's engine (see *STEAM-Engine*),

which he improved and brought to a far greater degree of perfection, both in its construction and powers, than it was before. Mr. Smeaton, during many years of his life, was a frequent attendant upon parliament, his opinion on various works begun or projected being continually called for. And in these cases the strength of his judgment and perspicuity of expression had full scope. It was his constant custom, when applied to plan or support any measure, to make himself fully master of the subject, to understand its merits and probable defects, before he would engage in it. By this caution, added to the clearness of his expression, and the integrity of his heart, he seldom failed to obtain for the bill which he supported the sanction of an act of parliament. No one was ever heard with more attention, nor had any one ever more confidence placed in his testimony. In the courts of law he had several compliments paid him from the bench by lord Mansfield and other judges, for the new light that he always threw upon difficult subjects. About the year 1785, the health of this excellent man began to decline, and he took the resolution to avoid all the business he could, in order that he might have leisure to publish an account of his inventions, improvements, and works, by which he conceived he should be doing a public benefit to his country and the world. In September 1792, he had a paralytic seizure, which put a period to his life in about six weeks.

Mr. Smeaton had a warmth of expression that might appear to those who did not know him, to border upon harshness, but those more intimately acquainted with him knew that it arose from the intense application of his mind, which was always in the pursuit of truth, or engaged in some difficult subjects. If he were sometimes apparently hasty and impetuous in his disposition, he would always listen to reason, and yield to the force of argument.

In all the social duties of life he was exemplary: his manners were simple, and his mode of life abstemious. He was singularly moderate in his pecuniary concerns. He was fond of science for its own sake, and spent much of his leisure in cultivating that of astronomy; for which purpose, he fitted up an observatory in his house, furnished with curious contrivances of his own invention. He was a friend and encourager of merit wherever he discerned it, and many persons were indebted to him for important assistance on their entrance into life. Mr. Smeaton was the institutor, in 1771, of a society of civil engineers, which was dissolved at his death, but afterwards renewed; they published, in 1797, a volume of his Reports. For his works in constructing bridges, mills, harbours, engines, &c. see his Reports, in 3 vols. 4to. Of his inventions and improvements of philosophical instruments, an idea may be formed from the list of his writings which is inserted in Hutton's Dictionary.

Smelting

SMELTING, among *Metallists*, the melting of a metal from the ore in a smelting furnace; in order to separate the metallic parts from the sulphur and arsenic, and the earthy and strong substances of all kinds with which they are combined.

Smelting, in propriety, is restrained to large works, in which ores from the mines are melted down and separated.

In speaking of works in a lesser way, we do not say smelting, but *melting*.

In the more precious metals this is called *refining*; which see. And smelting is most commonly applied to the reduction of iron ores.

The art of smelting the ores of all metallic substances was, probably, at first very imperfect; hence the use of iron has every where been of a more recent date than that of the other metals, because it requires the application of a much stronger fire to smelt the ores of iron than those of any other metal. We have no certain accounts when, or by whom, the several metals were discovered. Wallerius says, that, as far as he knew, Pliny was the first who enumerated the six metals; but they were certainly known long before his age, and were mentioned both by Homer and by Moses, a much more ancient author. (Numb. xxxi. 22.) From this testimony we may certainly infer, that all the metals, anciently mentioned, were known, at least in the country of the Midianites, above fourteen hundred and fifty years before the birth of Christ, or near nine hundred years after the deluge. Moreover, iron and copper were, without doubt, known before the deluge, and probably all the other metals, which are more easily extracted from their ores than the former.

In the time of Abraham, however, gold and silver were esteemed, as they are at present, precious metals (Gen. xxiii. 16. Gen. xiii. 2.); and hence it is reasonable to conclude, that Noah was able to instruct his descendants in the art of smelting metallic ores; this art was afterwards lost among the various colonies, which quitted the plains of Asia in search of settlements; and as the earth, soon after the deluge, and long before it could have been peopled by the posterity of Noah, must have become covered with wood, and in process of time different countries might have been cleared by setting the wood on fire, which might flux metallic ores contiguous to the surface of the earth, it is not improbable, that the first idea of smelting ores might have been thus suggested to many nations. See Creech's *Lucretius*, vol. ii. p. 572.

We may hence conjecture, that the first rude process, by which metals were extracted from their ores, was that of putting a quantity of ore upon a heap of wood, and setting the pile on fire, in conformity to the manner, in which ores were smelted during the burning of forests; but as the force of the fire is greatly diminished by the dispersion of its flame, and as the air acts more forcibly in exciting

fire, when it rushes upon it with greater velocity, it is likely that the heap of wood and ore would soon be surrounded with a wall of stone, in which sufficient openings would be left for the entrance of the air, and thus a kind of furnace would be constructed.

The Peruvians, we are told, had discovered the art of smelting and refining silver, either by the simple application of fire, or where the ore was more stubborn, and impregnated with foreign substances, by placing it in small ovens or furnaces on high grounds, so artificially constructed, that the draught of air performed the function of a bellows, a machine with which they were totally unacquainted. This method of smelting ores on high grounds, without the assistance of a bellows, or at least of bellows moved by water, seems to have been formerly practised in other countries as well as in Peru. There are several places in Derbyshire, called *boles* by the inhabitants, where lead has been anciently smelted, before the invention of moving bellows by water; these boles were always situated upon high grounds, and mostly upon that side of a hill which faces the west, probably because the wind proceeds most frequently from that quarter.

From a pig of lead, dug up in 1766 at one of these boles near Matlock, and bearing an inscription in relief, from which it appears to have been smelted in the age of Adrian; many of the boles in Derbyshire seem to be of high antiquity. However, this method of smelting ore by the variable action of the wind, being a very troublesome and precarious process, has been universally disused, and the more regular blast of a bellows has been introduced in its stead.

The invention of the bellows is attributed by Strabo to Anacharsis, the Scythian; but he was probably the improver of this machine; for Homer, who lived long before his time, describes Vulcan as employing twenty pair of bellows at once in the formation of the shield of Achilles. *Iliad*, lib. xviii. v. 470.

When the art of moving bellows by means of a water-wheel was first discovered, is uncertain; the ancients seem to have been unacquainted with it; but we learn from Agricola (*De Re Metal.* published in 1550, pp. 165. 338.) that it was very generally known, at least among the Germans, in his time; for he speaks of it often, without hinting at its being a recent invention. By this advantageous contrivance, however, the moderns have, in many instances, worked over again, with considerable profit, the heaps of iron and other kinds of slag, from which the metal has been but imperfectly extracted, before the moving of the bellows by water was discovered.

About fifty years ago, the blast, or hearth-furnace, was the only one in use for smelting lead-ore in Derbyshire. In this furnace, ore and charcoal, or ore, and what is called *white coal*, which is wood dried but not charred, being placed, in alternate layers, upon a hearth properly constructed, the fire is raised by the blast of a bellows, moved

by a water-wheel; the ore is soon melted by the violence of the fire, and the lead, as it is produced, trickles down a proper channel, into a place contrived for its reception. These ore-hearths are now very rare; though they are frequently applied to the extracting lead from the slag which is produced, either at the ore-hearth, or the cupola furnace, and they are then called *slag-hearths*, and the lead thus obtained is called *slag-lead*; the fire in a slag-hearth is made of the cinder of pit-coal instead of charcoal; the furnace called a *cupol*, or *cupola*, and *reverberatory furnace*, and by the Germans a *wind-furnace*, in which ores are melted by the flame of pit-coal, is said to have been invented about the year 1698, by a physician named Wright; though Becher may, perhaps, be thought to have a prior claim to its invention, or introduction from Germany. But whoever was the first inventor of the cupola, it is now in general use, not only in Derbyshire and other counties for the smelting of ores of lead, but both at home and abroad, where it is called the *English furnace*, for the smelting of copper ores. This furnace is so contrived, that the ore is melted, not by coming into immediate contact with the fuel, but by the reverberations of the flame upon it. The bottom of the furnace, on which the lead-ore is placed, is somewhat concave, shelving from the sides towards the middle; its roof is low and arched, resembling the roof of a baker's oven: the fire is placed at one end of the furnace, upon an iron grate, to the bottom of which the air has free access; at the other end, opposite to the fire-place, is a high perpendicular chimney; the direction of the flame, when all the apertures in the sides of the furnace are closed up, is necessarily determined, by the stream of air which enters at the grate, towards the chimney, and in tending thither it strikes upon the roof of the furnace, and being reverberated from thence upon the ore soon melts it. This furnace does not require the use of bellows, and may, therefore, be constructed any where. In smelting lead-ore, they generally put into the cupola furnace a ton of ore, previously beat small and dressed, at one time, which quantity they call a *charge*; and they work off three charges of ore in every twenty-four hours. In about six hours from the time of charging, the ore becomes as fluid as milk. In order to obtain the lead free from the slag which swims over it, the smelters usually throw in about a bushel of lime, which dries up the slag, and prevents its running out with the lead. The slag, thus thickened, is raked up towards the sides of the furnace, and the lead gushes out through a hole in one of the sides of the furnace, which having been properly stopped during the smelting of the ore, is opened for this purpose into an iron pot, from which it is laded into iron moulds, containing what they call a pig of lead; the pigs, when cold, being ordinarily stamped with the maker's name, are sold under the name of *ore-lead*. After the lead has all flowed out of the furnace, they stop up the tap-hole, and drawing down the slag and lime into the middle of the furnace, they raise the fire, till the mixture of slag and lime, which they simply term *slag*, is rendered very liquid; upon this mass they throw another quantity of lime, and proceed as before. When the lead thus obtained, amounting generally to twenty or thirty pounds, is let out of the furnace, a new charge of ore is put in and the operation renewed.

In order to spare the time and expence of fuel, they have, in some furnaces, lately contrived a hole, through which they suffer the main part of the liquid slag to flow out, before they tap the furnace for the lead; upon the little remaining slag they throw a small portion of lime, and draw the mixture out of the furnace without smelting it. This kind of furnace they have nicknamed a *maccaroni*.

Dr. Watson has suggested some improvements in the construction of this furnace, and in the process of smelting above described. He proposes to substitute an horizontal chimney in the place of the perpendicular one now in use, and that the end farthest from the fire should be turned up by a tube of earthen-ware, or otherwise; so that the sulphureous acid, set at liberty during the burning of the sulphur, may issue out in a direction parallel to the flue of the chimney, and at the distance of about one foot and a half above it. Let a number of large globular vessels be made either of glass or lead, each of which must have two necks, so as to be capable of being inserted into one another: let these vessels be placed in the flue of the chimney, the neck of the first being inserted into the above-mentioned tube, and the neck of the last being left open, for fear of injuring the draught of the furnace. Let each of these globular vessels contain a small quantity of water, in which case, he apprehends, that the heat of the flue will raise the water into vapour, and that this watery vapour will be the means of condensing the sulphureous acid vapour, in such a degree as to render the undertaking profitable. When the sulphur is all consumed, the draught of the furnace may be suffered to have its ordinary exit at the end of the horizontal chimney, by a very slight contrivance of a moveable damper.

The same ingenious writer also observes, that very sulphureous ore should be roasted for a long time with a gentle heat. He also proposes to leave as little lead as possible in the slag; for this purpose he suggests, that it might be useful to throw a quantity of charcoal-dust upon the liquid scoria in the cupola furnace, in order that the calcined lead might be converted into lead, by uniting itself to the inflammable principle of the charcoal; and that it might be also useful to flux sulphureous lead-ores in conjunction with the scales or other refuse pieces of iron, or even with some sorts of iron-ore.

The smelter might farther find it worth his while to reduce the slag into a powder by a stamping mill, or to grind it by any other contrivance, and then he may separate the stony part of the slag from the metallic, by washing the whole in water, inasmuch as the metallic part is heavier than the other. Watson's Chem. Ess. vol. iii. p. 253, &c.

The other furnaces used in smelting are supplied with large bellows, moved by the arbor of a wheel, which is turned round by a current of water. These have obtained different names, according to some difference in their construction. Their greater or less height gives occasion also to the distinction of *high furnaces* and *middle furnaces*. The high furnaces are of modern invention; they were first introduced at Mansfeld in 1727, and are now used in almost all countries where ores are smelted, as in Saxony, Bohemia, Hungary, &c. They contribute, by their great height, being above eighteen feet high, which allows the ore to undergo a roasting by different degrees of heat before it is melted, to simplify and diminish the labour. They are chiefly employed for crude fusions, and particularly for the slate copper-ore.

In order to facilitate the extraction of metallic substances from the ores and minerals containing them, some operations, previous to the fusion or smelting of these ores and minerals, are generally necessary. These operations consist of, 1. The *separation* of the ores and metallic matter from the adhering unmetallic earths and stones, by hammers, and other mechanical instruments, or by washing with water. 2. Their *division* or reduction into smaller parts by contusion and trituration, that by another washing with water they may be more perfectly cleansed from extraneous matters, and rendered fitter for the subsequent operations. 3. *Roast-*

ing, or *calcination*, the uses of which operation are to expel the volatile, useless, or noxious substances, as water, vitriolic acid, sulphur, and arsenic; to render the ore more friable and fitter for the subsequent confusion and fusion; and, lastly, to calcine and destroy the viler metals; for instance, the iron copper-ores, by means of the fire, and of the sulphur and arsenic. Stones, as quartz and flints, containing metallic veins or particles, are frequently made red-hot, and then extinguished in cold water, that they may be rendered sufficiently friable and pulverable, to allow the separation of the metallic particles.

Roasting is unnecessary for native metals; for some of the richer gold and silver-ores; for some lead-ores, the sulphur of which may be separated during the fusion; and for many calciform ores, as these do not generally contain any sulphur and arsenic.

In the roasting of ores, the following attentions must be given: 1. To reduce the mineral previously into small lumps, that the surface may be increased; but they must not be so small, nor placed so compactly, as to prevent the passage of the air and flame. 2. The larger pieces must be placed at the bottom of the pile, where the greatest heat is. 3. The heat must be gradually applied, that the sulphur may not be melted, which would greatly retard its expulsion; and that the spars, fluors, and stones, intermixed with the ore, may not crack, fly, and be dispersed. 4. The ores not thoroughly roasted by one operation must be exposed to a second. 5. The fire may be increased towards the end, that the noxious matters more strongly adhering may be expelled. 6. Fuel which yields much flame, as wood and fossil coals free from sulphur, is said to be preferable to charcoal or coaks. Sometimes cold water is thrown on the calcined ore at the end of the operation, while the ore is yet hot, to render it more friable.

No general rule can be given concerning the duration or degree of the fire, these being very various according to the difference of the ores. A roasting during a few hours or days is sufficient for many ores; while some, such as the ore of Rammelsberg, require that it should be continued during several months.

Schlutter enumerates five methods of roasting ores. 1. By constructing a pile of ores and fuel placed in alternate strata, in the open air, without any furnace. 2. By confining such a pile within walls, but without a roof. 3. By placing the pile under a roof, without lateral walls. 4. By placing the pile in a furnace consisting of walls and a roof. 5. By roasting the ore in a reverberatory furnace, in which it must be continually stirred with an iron rod.

Several kinds of *fusions of ores* may be distinguished. 1. When a sulphureous ore is mixed with much earthy matter, from which it cannot be easily separated, by mechanical operation, it is frequently melted, in order to disengage it from these earthy matters, and to concentrate its metallic contents. By this fusion, some of the sulphur is dissipated, and the ore is reduced to a state intermediate betwixt that of ore and of metal. It is then called a *matt* (lapis sulphureo-metallicus), and is to be afterwards treated like a pure ore by the second kind of fusion, which is properly the smelting, or extraction of metal by fusion. 2. By this fusion or smelting, the metal is extracted from the ore previously prepared by the above operations, if these be necessary.

The ores of some very fusible metals, as of bismuth, may be smelted by applying a heat sufficient only to melt the metals, which are thereby separated from the adhering extraneous matters. This separation of metals by fusion, without the vitrification of extraneous matters, may be

called *eliquation*. Generally, a complete fusion of the ore and vitrification of the earthy matters are necessary for the perfect separation of the contained metals. By this method, metals are obtained from their ores, sometimes pure, and sometimes mixed with other metallic substances, from which they must be afterwards separated. To procure this separation of metals from ores, these must be so thinly liquefied, that the small metallic particles may disengage themselves from the scoria; but it must not be so thin as to allow the metal to precipitate before it be perfectly disengaged from any adhering extraneous matter, or to pervade and destroy the containing vessels and furnace. Some ores are sufficiently fusible; but others require certain additions, called *fluxes*, to promote their fusion, and the vitrification of their unmetallic parts; and also to render the scoria sufficiently thin to allow of the separation of the metallic particles.

Different fluxes are suitable to different ores, according to the quality of the ore, and of the matrix, or stone adherent to it.

The matrixes of two different ores of the same metal frequently serve as fluxes to each other; as, for instance, an argillaceous matrix with one that is calcareous; these two earths being disposed to vitrification when mixed, though each of them is singly infusible. For this reason, two or more different ores to be smelted are frequently mixed together.

The ores also of different metals require different fluxes. Thus, calcareous earth is found to be best suited to iron ores, and spars and scoria to fusible ores of copper.

The fluxes most frequently employed in the smelting of ores, are calcareous earth, fluors or vitreous spars, quartz, and sand, fusible stones, as slates, basaltes, the several kinds of scoria, and pyrites.

Calcareous earth is used to facilitate the fusion of ores of iron, and of some of the poorer ores of copper, and, in general, of ores mixed with argillaceous earths, or with felspar. This earth has been sometimes added with a view of separating the sulphur, to which it very readily unites: but by this union, the sulphur is detained, and a hepar is formed, which readily dissolves iron and other metals, and so firmly adheres to them, that they cannot be separated without more difficulty than they could from the original ore. This addition is therefore not to be made till the sulphur be previously well expelled.

Fluors, or fusible spars, facilitate the fusion of most metallic minerals, and also of calcareous and argillaceous earths, of steatites, asbestos, and of some other infusible stones, but not of siliceous earths without a mixture of calcareous earth.

Quartz is sometimes added in the fusion of ferruginous copper ores, the use of which is said chiefly to be, to enable the ore to receive greater heat, and to give a more perfect vitrification to the ferruginous scoria.

The fusible stones, or slates, basaltes, are so tenacious and thick when fused, that they cannot be considered properly as fluxes, but as matters added to lessen the too great liquidity of some very fusible minerals.

The scoria obtained in the fusion of an ore is frequently useful to facilitate the fusion of an ore of the same metal, and sometimes even of the ores of other metals.

Sulphurated pyrites greatly promotes the fusibility of the scoria of metals, from the sulphur it contains. It is chiefly added to difficultly fusible copper ores, to form the sulphureous compounds called *matts*, that the ores thus brought into fusion, may be separated from the adhering earthy matters, and that the ferruginous matter contained in them may

be destroyed, during the subsequent calcination and fusion, by means of the sulphur.

As in the ores called *calciform*, the metallic matter exists in a calcined state; and as calcination reduces the metals of mineralised ores (excepting the perfect metals) to that state also; therefore all calciform and calcined ores require the addition of some *inflammable substance* to reduce them to a metallic state. In great works, the charcoal or other fuel used to maintain the fire, produces also this effect.

Metals are sometimes added in the fusion of ores of other more valuable metals, to absorb from these sulphur and arsenic. Thus, iron is added to sulphurated cupreous and silver ores. Metals are also added in the fusion of ores of other more valuable metals, to unite with and collect the small particles of these dispersed through much earthy matter, and thus to assist their precipitation. With these intentions, lead is frequently added to ores and minerals containing gold, silver, and copper.

Ores of metals are also sometimes added to assist the precipitation of more valuable metals. Thus, antimony is frequently added to assist the precipitation of gold intermixed with other metallic matters. Macquer's Chem. Dict. Eng. edit. art. *Smelting*, note *m*. See COPPER, GOLD, IRON,

LEAD, SILVER, TIN, &c. See also Schlutter's Treatise on the Smelting of Ores, translated from the German into French by M. Hellot, and Chem. Dict. art. *Smelting*, Eng. ed. notes *n*, *o*, *p*, *q*.

The following simple method of smelting is practised by the natives of the province of Mekran in Persia; which, although it may, at times, leave a trifling portion of the earth mixed with the metal, is, from its ingenuity, worthy of notice. When a sufficient quantity of the ore is collected, it is placed upon a pile of wood, which is set on fire, and constantly replenished with fresh fuel, until the ore melts and falls to the bottom, when it is separated from the ashes, and found to be considerably clearer than when first taken from the mine. It is then placed in a pit, made of earthen tiles, so constructed as to admit a fire under it. The ore is again melted in this pit, and a considerable quantity of the dross and dirt removed, by skimming the surface. After this process, the metal is lifted out in a liquid state, poured into hollow cylinders of clay, and then sold.

SMELTING-HOUSE, a house where they run and melt the ore into lead: one of these will run a ton in ten or twelve hours; but a fodder is their usual day's work, that is, twenty-two hundred and an half weight.

Soap

SOAP, in *Chemistry*, is a name for those bodies which are compounds of the alkalies with fat and the fixed oils. The earths and the other metallic oxyds also combine with fat and oils, forming neutral compounds. The former have

been called earthy, and the latter metallic soaps.

The soaps formed by the alkalies have the distinguishing character of being soluble in water and alcohol. The earthy

soaps are perfectly insoluble. And since any of the earths have a stronger attraction for oil than the alkalies, the alkaline soaps are always decomposed by the earths. This occasions the curdy appearance when soap is used with water containing any earthy or metallic salt. It is from this quality that waters are said to be hard.

The earthy soaps are of a greyish-white colour, of a curdy appearance. The metallic soaps are of different colours. Both these and the earthy soaps are formed by adding a solution of an alkaline soap to a solution of an earthy or metallic salt. A precipitate is formed, which is the soap to be obtained. With a solution of iron containing the red oxyd, the soap is of an orange-red colour. It has the consistency of a salve or plaster, but by exposure to the air it becomes dry and friable, but may be softened by heat. When a similar solution of soap is added to a solution of sulphate of copper, a green soap is formed, which is a fluxible mass like wax. Corrosive sublimate, treated in this manner, gives a red soap. All the metallic oxyds may be combined with fat or oil in a similar way.

SOAP, in the *Manufactures and Domestic Economy*. This is confined to soaps made with the fixed alkalies, combined with different kinds of fat and oil. These, in the manufacture of soap, are divided into two principal varieties, viz. hard and soft.

1. *Hard Soap*.—The alkali employed for hard soap is soda, generally obtained from the different sea vegetables, and called by different names, according to the name of the plant in different countries. Most of the *algæ*, but particularly the *fucus* and *salsola*, afford soda by burning. The vegetables are first dried, and then burnt in pits formed with loose stones. The earthy matter and the soda, with some neutral salts, fuse into a crude mass, in which state it is sold. This substance is furnished in great abundance from the Highlands of Scotland, under the name of *kelp*, and from Alicante in Spain, under the name of *barilla*. In France it is known by the name of *varrec*; this being the name of the plant from which it is generally produced there.

It is commonly, however, in this state that it comes to the soap-maker, varying frequently in its value, and often occasioning much uncertainty in its employment. It should be the first business, therefore, of the manufacturer, to assay the substance from which he gets his alkali, even before he purchases it. For this purpose a given quantity should be dried and weighed. After reducing it to powder, it must be treated with hot rain-water, till the water coming from it has no taste, reserving all the portions of water added from time to time. Concentrate this liquid by evaporation, till the quantity of liquid is not more than three times the weight of the quantity taken to be assayed. Now weigh out a quantity of sulphuric acid, say half the weight of the assay. From this quantity take small portions at a time, and add them to the solution above-mentioned, stirring it at the same time with a wooden rod. When the escape of gas begins to diminish on the addition of fresh acid, let the additional portions be very small. Now take bits of paper stained blue with litmus: on dipping one into the liquid, if more acid is wanting, the paper will not be changed, but the moment the paper is turned red by the liquid, cease to add sulphuric acid. Let the remaining acid be now weighed, in order to know what has been used, and note this down. Now take pure sal soda (carbonate of soda) in well-formed crystals, exactly of the same weight with the first assay, and dissolve it in three times its weight of pure water. Weigh out the same quantity of sulphuric acid as before, and just follow the same steps as above directed, till the litmus paper just turns red, then weigh the remaining acid, to obtain the quan-

tity used, and note down as before. Then say, as the acid consumed by the sal soda is to that consumed by the assay, so is 100 to a number which will give the *per centage* of carbonate of soda contained in the crude alkali. Thirty *per cent.* of the carbonate of soda so indicated will be real soda, the only substance which combines with the fat to form soap. When the exact value of the alkali is known, it is then to be treated as follows, to prepare it for mixing with the fat.

The kelp or barilla is first to be pounded, and then mixed with one-fifth its weight of quicklime, in a large vat. These vats are generally three or four in number to each boiler. They are frequently made with brick-work, from four to five-feet cubes, but sometimes of cast-iron. Besides these vats for the infusion of crude alkali, each of these has a similar cavity under it. The bottom of the vat is even with the ground, the under vat being sunk below, and is intended to receive the liquor which runs from a plug-hole in the upper vat, when the infusion has gone on to a certain extent. One of these vats, with its under reservoir, is sufficient for one boiling, but they are generally all at work, in order to give time for the solution of the alkali from the crude mass.

In charging a vat, the barilla, kelp, or potash, and sometimes mixtures of these, are first coarsely powdered, and mixed with quicklime also coarsely powdered; some water is then thrown upon these to slake the lime. In the side of the vat some straw is first placed about the plug-hole, to prevent bits from passing through. The vat is now charged, and water poured upon the materials till it stands considerably above the solid mass. After standing several hours the plug is withdrawn, to let out the solution into the lower reservoir. The plug is now returned, and fresh water poured upon the materials. Some or all the first ley is now removed into one of the other lower reservoirs before the second infusion is drawn off. This is done, that the soap-boiler may always have at command two leys of different degrees of strength, as in the course of every boiling he finds it necessary to use sometimes the weak and at other times the strong.

The number of waters to be added to the materials depends upon the judgment of the workman, who by his taste can tell when the water has dissolved the whole of the alkali. The times of charging the vats are irregular with respect to the times of charging the boiler. Some one of the vats is constantly employed, in order to insure a constant supply of the ley.

The boilers are made to hold from about 20 to 25 cwt. of soap; they are made in two parts, the lower part being about three feet in diameter, and the same in length: under the bottom of this the fire acts. The top part has a flange, to which the upper part is screwed. The latter is nearly an hemisphere, rising above the floor just sufficient to allow the workman to stir the soap when he stands up.

The ley being ready to lade out of the reservoir, which is near to the boiler, the tallow or oil first weighed is put in. When it is sufficiently melted, the workman begins by adding the ley, and stirring the mixture. The alkali and the oil soon begin to unite, forming a milky fluid. As more ley is added, and the stirring continued, the liquid thickens. This is continued generally for 30 hours, and frequently more, till small portions of the soap, taken out from time to time, assume a proper consistence, which the workman by constant experience understands. He now adds a quantity of common salt, which has the effect of separating the watery part from the soap, which contains a portion of neutral salts, that existed in the crude alkali, and sometimes also free alkali, especially when more than enough has been added. The fire is now to be withdrawn, and the mass left to cool. The watery part will be found at the bottom, and

requires to be pumped out by a pump, which is a fixture on the side of the boiler. When this has been removed the fire is rekindled, and if the mass does not melt freely, a little water is added. As soon as the whole becomes liquid, and is made uniform by agitation with wooden poles, the fire is again withdrawn, and the mass allowed to assume a proper consistence for lading. It is laded into square moulds: these are composed of a number of strata lying one upon another, so that when the soap has become solid, each layer of frame-work can be removed, beginning at the top, and the soap is cut into cakes with a piece of small brass wire at every interval: these cakes are afterwards cut into square prismatic pieces, in which state they are sold.

Some manufacturers proceed in a different manner in boiling the soap. In the method above described, and which is practised by a judicious soap-boiler in Derby, the watery part, or what is called the spent ley, is not separated till all the ley is added. This method is called close working, because the liquid is of an uniform thickness all the time, till the salt is added: it then assumes what is called the granular form, in which the watery part is separated from the soap, like the whey and the curd in making cheese. This arises from the soap being insoluble in salt-water. In this state the soap is said to be open, to distinguish it from the state in which it exists before the salt is added, and in which the soap is said to be closed. In the open working the common salt is added at several intervals, in order to keep the soap separated from the water. The fire is also withdrawn several times, and as many times the spent leys are pumped off. After each time, except the last, fresh ley is added and the stirring repeated. The proper state for the soap is known by the appearance of the bubbles. The very hard soap, or that which is made with all soda, is not the most convenient for practice; it is neither so fit for washing the hands, nor so easily reducible to a pulpy state for the different manufactures in which it is employed. The hard white soap, produced in the manufactory above alluded to, is in great repute from its whiteness and its proper consistency. This soap is formed with tallow and a mixture of soda and potash. The boiler holds from about 25 to 27 cwt. of soap. The following are the average proportions of the materials employed; 13 cwt. 2 qr. 16 lbs. of tallow, 5 cwt. 3 qr. 12 lbs. barilla, 3 cwt. 2 qr. 6 lbs. American potash, 4 cwt. 2 qr. 7 lbs. quicklime, and 3 qr. 16 lbs. common salt (muriate of soda.) These materials produce 1 ton 4 cwt. 0 qr. 1 lb. of white soap. The lime, the barilla, and the potash, are mixed together, and placed in the vat already described. In order to furnish the ley which is added to the melted tallow, the lime is employed merely to rob the potash and soda of their carbonic acid, and of course does not enter into the composition of the soap. The neutral salts, which both the barilla and potash contain, are pumped out with the spent leys with a portion of uncombined alkali: of this we shall say something hereafter.

Hence it will appear, that the soap is a compound of pure alkali, with the fat, and a portion of water.

In the making of soap, as in all other chemical combinations, the proportions appear to be definite. Every soap-boiler knows, that where too much ley is added to the fat, the excess will be found in the watery part under the soap; and that if the fat were in excess, the soap would be greasy to the feel, and would otherwise shew the presence of uncombined fat. Hence it will be found on analysis, that the proportions will be uniform, because they are definite. The quantity of soda which combines with olive-oil and tallow,

is about 30 of the former to 212 of the latter; and since an atom of potash is to that of soda as 29.25 to 44.5, 45 of potash will combine with 212 of oil or tallow.

The following is an analysis of soap by Darcet, Lelievre, and Pelletier:

Oil	-	
Soda	-	
Water	-	
		100

If the alkali were potash instead of soda, then the proportions would be,

Oil	-	-	-
Potash	-	-	-
Water	-	-	-
			100

In the first of these analyses, the soda is to the oil as 85 to 609, or as 1 to 7.28 nearly. In the second, the potash is to the oil as 12.3 to 58.4, or as 1 to 4.6 nearly. The specimen of soap before alluded to contains a mixture of potash and soda. The 3 cwt. 2 qr. 6 lbs. of American potash, according to the average value of that article, ought to give 2 cwt. 2 qr. of pure potash. By the above analysis, the 1 ton 4 cwt. 0 qr. 1 lb. of soap ought to contain 7 cwt. 1 qr. 7 lbs. of water. There ought to be therefore only 16 cwt. 3 qr. 21 lbs. of the alkali and tallow. It appears, that in forming this specimen of soap, 100 lbs. of common salt were added, which gives to the soap 55.5 lbs. of soda, and takes away from it 83.25 lbs. of potash. Hence, the alkali resulting from the potash in this soap will be 1 cwt. 3 qr., and 55.5 lbs. of soda derived from the common salt, or 2 qr. 4 lbs. nearly. In order to know what soda is derived from the barilla, we must subtract the tallow and the alkali from the whole; that is (16 cwt. 2 qr. 27 lbs.) 1 cwt. 3 qr. of potash, 2 qr. of soda, and 13 cwt. 2 qr. 16 lbs. of tallow, will leave 3 qr. 6 lbs. of soda derived from the barilla.

The proportions of the soap in question will, therefore, be, in 2689 lbs. of soap,

Tallow	1528	or
Soda	-	146
Potash	-	196
Water	-	819

100

This result, although it contains a little too much of the mixed alkali to correspond with theory, is strikingly near the truth. We may therefore conclude, that soap, in general, contains from 8 to 12 per cent. of alkali, as more or less of each prevails, and about 30 per cent. of water. The hardest white soap made with soda would contain 8 per cent.; and the soft soap, in which potash alone is used, would be a little more than 12 per cent.

In the above specimen of hard soap, it will be seen that 398 lbs. of crude potash furnish 280 lbs. of real alkali, which is seven-tenths of the whole. With this were employed 656 lbs. of barilla, which furnish 90 lbs. of real alkali. Now 192 lbs. of American potash will produce 135 lbs. of pure potash, and this will disengage from 126 lbs. of muriate of soda, or common salt, 90 lbs. of pure soda. Hence 192 lbs. of American potash and 126 lbs. of salt will produce as much soda as 656 lbs. of barilla.

This weight of barilla, at the present price, costs 10*l.* 5*s.* : 192 lbs. of potash will now cost 6*l.* 17*s.* ; and 126 lbs. of common salt, 1*l.* 17*s.* These two sums are 8*l.* 14*s.* The saving, therefore, in employing potash and common salt, in making even the best hard white soap, instead of barilla, is nearly 5 per cent. But if the two alkalies are to be contained in equal proportions, then about half the common salt only need be used, and the saving will be very considerable. It will also appear evident, that soap may be made of any degree of hardness, by using more or less of common salt with the potash ; and that if no salt at all be used, the soap will be soft.

The difference of price between barilla and potash is often much more than at present in favour of using potash : this will make the saving above mentioned more conspicuous.

It must also be remembered, that some salt is always used for the purpose of separating the spent leys from the soap. This has been stated at about three-quarters of a cwt. to 24 cwt. of soap. It seems that a solution of salt of this strength does not dissolve soap.

Hard Soap, Yellow.—This soap is formed of similar proportions of soda and tallow with the lye ; but it also contains rosin, and sometimes palm oil.

The following are the average proportions of the materials for making yellow soap, which may be relied upon.

Tallow.	Rosin.	Palm Oil.	Barilla.	Potash.	Lime.	Soap produced.
Cwt. qr. lb.						
13 0 11	3 2 18	1 0 0	6 2 14	1 0 16	5 0 9	26 1 21

The whole weight of the materials, exclusive of the lime, and the refuse of the potash and barilla, is equal to 24 cwt. 0 qr. 1 lb. ; the soap, independent of the water it contains, is 18 cwt. 0 qr. 25 lbs. : thus, taken from 24 cwt. 0 qr. 1 lb. leaves 5 cwt. 3 qr. 4 lbs. for the refuse of the tallow, rosin, and palm oil. That the tallow must make much waste will be easily conceived, from the most inferior kind being used. The rosin and oil must also yield much refuse. This refuse is found all together at the bottom of the pan after boiling, and is known in the manufactories under the name of *nigre*.

In boiling the yellow soap, the rosin, oil, and tallow are put into the boiler first. The ley is prepared in a similar vat, and managed in other respects in the same mode as in forming the white soap.

The manner too of adding the ley from time to time, and the stirring, are just kept up in a similar way, till the fatty matter is fully saturated. The time required for boiling the quantity of soap stated above, is sometimes as much as three weeks, during which time it is kept in what is called the open state, that is, the watery part is completely separated from the soap. It would appear that this soap requires merely the presence of the neutral salts in ley to keep it in the open state. This arises probably from this being a less perfect soap, and less soluble in water. The soap appears in small lumps, perfectly detached from the fluid. At the end of every day the soap is allowed to cool, when the thin part sinks to the bottom : this is spent ley, and is pumped off every morning. The fire is again raised, and fresh leys added : the boiling and stirring go on again. This action is repeated till the fat is said to be killed. This, as we have observed, takes sometimes fifteen or twenty days. When this change is complete the fire is withdrawn, and the mass allowed to cool : the last ley is pumped out. The addition of a little water, and the fire being raised, allow the soap

to be dissolved, and the refuse, which is principally the substance we have called *nigre*, is left at the bottom, perfectly distinct from the soap. When the soap is of a proper consistence for caking, it is transferred to the moulds, where it is treated in a manner similar to that already described in the white soap.

It is a question, whether making this inferior soap is so profitable to the manufacturer as is supposed. It has appeared, that in making the quantity of soap above stated, which is 26 cwt. 0 qr. 21 lbs., there are 5 cwt. 3 qr. 4 lbs. of refuse, which is principally in the *nigre*. This refuse will be found very trifling in the white soap ; we think not more than $\frac{1}{4}$ th of the weight of the soap. It will be evident, that in making the yellow soap, a great quantity of matter is used which never combines. Would it not be more economical to purify these materials before hand?

Soft Soap.—This differs in its composition from hard, in containing no alkali, but potash. We have seen that hard soap may be made not only with pure soda, as is the case in the manufactories in the south of France, but that a tolerably hard soap, much better fitted for practice, is made with about equal portions of potash and soda.

Soft soap made with colourless fat, such as tallow, is a white unctuous substance, about the consistency of lard. If the fat be coloured, the soap partakes of the same. In France and other parts of the continent, it is generally coloured, sometimes with metallic oxyds. Those made with yellow oil are sometimes coloured with indigo, which gives them a green colour. The oils employed are seldom olive-oil, but the cheaper oils, such as rape-oil, the oil of hemp-seed, lint-seed, and others.

In Holland it was made with whale-oil. This oil was forbidden on some parts of the continent, on account of its disagreeable smell. In this country, however, all the soft soaps are made with whale-oil, which gives a transparent mass of a yellow colour. In commerce, however, we do not find it uniform in its colour. Besides the yellow part, it appears interspersed with white spots, giving the whole a strong resemblance to the inside of a dried fig.

The proportions of potash and oil, for forming soft soap, will be easily inferred from what has been observed in the proportions of the other soaps. The white specks are produced by adding a portion of tallow to the oil, when the boiler is charged. This addition does not improve the soap, but habit in commerce has rendered it indispensable. The ley is prepared by adding to the potash about three-fourths its weight of quicklime, and the process is continued as directed in making the hard soap, using the same apparatus. The ley, when prepared, is to be added to the oil and tallow in the boiler at intervals, similar to those in making the hard soap, and the stirring kept up in the same way, till the mass assumes a proper consistency. The experienced soap-maker will judge, when the materials are in proper proportions, by the appearance of the soap when boiling ; hence he knows when to cease to add more ley. Should a stranger to the process of making either kind of soap have to perform the task, he would require to know the proportions in which the alkali ought to bear to the oil. He would weigh his oil or tallow when he put it into the boiler ; he will assay his ley by the method laid down in the commencement of this article, and by that means know how much real alkali is contained in a given measure of his ley. He will by this means know nearly when he had added a sufficient quantity of ley to saturate the oil or fat. In the soap made with soda, the real alkali must be to the oil as 1 to 7.28, and that with all potash must be as 1 to 5.1 nearly. This of course will be the proportion for soft soap. When the soft soap is

of a proper consistency for caking, it is poured into barrels, in which it is sold.

Soaps, particularly the hard, are frequently reduced in their value, by the fraudulent practice of keeping them wet. The common or proper state is when they contain about 30 *per cent.* of water; but they may, by a nefarious management, be made to contain 60 *per cent.* which is a great imposition. This fraud, like many others, is detected when it is too late. It is found to lose weight rapidly by exposure to the air.

Before we close this article, we may point out some means of economizing the use of the alkali in soap-making, which, in very extensive manufactories, is worth attending to. In the first place, it should be observed, that the spent leys always contain free alkali, and it is generally added a second time, in order that as much as possible of it may be taken up. It is found, however, by experience, that some will still be found in solution, which the fat will never take up. This is owing to the same liquid containing several neutral salts in solution. If this liquor be evaporated to a certain extent, and set to cool in shallow vessels, the neutral salts will crystallize and separate from the liquid to a certain extent. The liquid part may then be evaporated a second time, and again crystallized. The liquid, after these salts have been separated, may now be added to the fat, and the alkali will combine with it. If barilla or kelp is the alkali, then the liquid ought to have a little lime added, which evaporating, serves to take the carbonic acid from the soda. Without this precaution the carbonate of soda would crystallize with the other salts. With potash this precaution is unnecessary.

The salts which are separated from barilla and kelp are chiefly muriate and sulphate of soda. The former may be used as a substitute for salt in the last part of the process of boiling. The sulphate of soda may be fused with sawdust or powdered coal in a reverberatory-furnace. The sulphuret of soda is produced, from which the alkali may be recovered. Perfumed soaps are easily formed by adding the different essential oils while the soap is in a liquid form, but not while very hot, because the perfume would evaporate. The saponaceous liquid, called milk of roses, is formed by mixing the liquid obtained by exposing potash to the air with rose-water, and then adding this to oil of almonds, till the mixture becomes milky without being greasy.

Ball Soap, commonly used in the North, is made with lees from ashes and tallow. The lees are put into the copper, and boiled till the watery part is quite gone, and there remains nothing in the copper but a sort of saline matter (the very strength or essence of the ley); to this the tallow is put, and the copper is kept boiling and stirring for above half an hour, in which time the soap is made; and then it is put out of the copper into tubs, or baskets, with sheets in them, and immediately (while soft) made into balls. Note, it requires nearly twenty-four hours, in this process, to boil away the watery part of the ley.

The simplest, and upon the whole the most beautiful, soap, is the fine white soap prepared from olive-oil and soda, extracted from the best barilla, which is manufactured largely in the countries where the olive grows; particularly in the south of France, for which Marseilles is the most celebrated, in some parts of Italy, and in Tripoli. A similar, but more expensive soap, is made of soda and oil of almonds for medicinal purposes. (See *Sapo Amygdalinus*.) What is called in our country "Windfor soap" is of this kind, prepared with either of the above-mentioned oils. Common soap is manufactured principally by our soap-boilers from tallow or any other fat; and the alkali em-

ployed is either barilla or pearl-ash, or a mixture of the two, according to the price and the practice of the manufacturer. But in order to obtain a stiff salt, recourse is had to the action of common salt, as we have already mentioned. The olive-oil, or Marseilles and other soaps, are sometimes artificially "marbled," or streaked throughout their whole substance with red or blue veins. This soap is harder than the white soap of the same materials, because it requires to be dried to a greater degree in order to take the marbling. This is performed, by adding to the soap, as soon as it is completely made and separated from the spent ley, a fresh quantity of ley, and immediately afterwards a solution of sulphate of iron. A decomposition between the two takes place, and a black oxyd of iron is separated, which is entangled within the liquid soap. The boiler is then cooled, and the ley which settles is drawn off; after which the soap is again melted. A workman then stands over the boiler, and stirs the soap with a wooden instrument, while another throws in at intervals a quantity of colcothar, or brown-red oxyd of iron, ground up with water into an uniform liquid. This diffuses both the oxyds through the soap, which is then cooled and framed. This process requires some manual dexterity, so that the ingredients may be stirred together, and the marbling sufficiently diffused through the whole mass, without mixing it completely.

Soap is much used in washing and whitening linens, cleansing woollen cloths from oil, whitening silk, and freeing it from the resinous varnish with which it is naturally covered; and for various other purposes, by the dyers, perfumers, hatters, fullers, &c.

The alkaline lixiviums, being capable of dissolving oils more effectually than soap, might be employed for the same purposes; but when this activity is not mitigated by oil, as it is in soap, they are capable of altering, and even destroying entirely, by their causticity, most substances, especially animal matters, as silk, wool, and others; whereas soap cleanses from oil almost as effectually as pure alkali, without danger of altering or destroying, which renders it very useful.

The manufacture of soap in London, first began in the year 1524; before which time this city was served with white soap from foreign countries, and with grey soap, speckled with white, from Bristol, and sold for a penny a pound, and also black soap for a halfpenny the pound.

Soap, in the *Materia Medica*. Soaps, both hard and soft, have been applied to medical use. Well made hard soap, fit for medical use, has very little odour, and a nauseous alkalescent taste; is white, and of a firm consistence; does not feel greasy, and is devoid of any saline efflorescence on the surface. With water it forms a milky opaque solution; and with alcohol a nearly transparent, somewhat gelatinous, solution. It is decomposed by all the acids, and by many neutral salts, which combine with the alkali and form new compounds; hence hard water which contains sulphate of lime does not properly dissolve soap. According to the experiments of Darcet, Lelievre, and Pelletier, (stated in the preceding article,) 100 parts of newly made soap consist of 60.94 oil, 8.56 alkali, and 0.503 water: but part of the water is lost by keeping, and the soap becomes lighter.

Hard soap, triturated with vegetable resins and thick balsams, incorporates with them into a compound; soluble, like the soap itself, in watery liquors; hence it proves an useful ingredient in resinous pills, which of themselves are apt to pass entire through the intestines, but by the admixture of soap become dissoluble in the stomach. It renders

unctuous and thick animal matters diffoluble in like manner in aqueous fluids, and hence may be presumed to act as a menstruum for these kinds of substances in the body, that is, to attenuate viscid juices and resolve obstructions: such, in effect, are the virtues which it appears to exert in cachectic, hydropic, and icteric cases, in which last, particularly, its aperient and resolvent powers have been often experienced. Solutions of it have been likewise found to dissolve certain animal concretions of the harder kind, as the filaments which are sometimes seen floating in the urine of rheumatic and arthritic persons, the matter secreted in gouty joints, and the more compact urinary calculus; on these substances (at least in the latter), though soap of itself acts more languidly than lime-water, yet, when joined to that menstruum, it remarkably increases its activity; the dissolving power of a composition of the two being, according to Dr. Whytt's experiments, considerably greater than that of the soap and lime-water unmixed: of the good effects of these medicines in calculous cases there are several instances; but what their effects may be in gouty and rheumatic ones is not yet well known. See LITHONTRIPTICS, STEPHENS'S *Medicine*, &c. and STONE.

Soap is regarded, in the materia medica, as purgative and lithontriptic; externally applied it is stimulant and detergent. For internal use the hard soap only is employed. It is occasionally ordered in habitual costiveness, and in jaundice, combined with rhubarb, or some bitter extract; but its power as a purgative is very limited, and it cannot act in any other way in relieving jaundice. It is more useful in calculous habits, in which, however, its action is altogether confined to the stomach; for as soap is decomposed by the weakest acids, its alkaline base corrects the acidity so prevalent in the stomachs of calculous patients, and thus at least assists in checking the increase of the disease. Soap is also beneficial in decomposing metallic poisons when taken into the stomach; and, as it is the antidote which can most readily be procured, should always be early resorted to. It is necessary in this latter case to give it in solution; of which a teacupful should be drunk at short intervals, till the effects expected from it be produced. In other cases it is preferable to give it in substance. The dose may be from grs. v to 3ss, made into pills.

As an external remedy, soap is efficaciously used in frictions to sprains and bruises; and much benefit has been derived from rubbing the tumid bellies of children labouring under mesenteric fever, with a strong lather of soap every morning and evening.

From the properties of soap we may know, that it must be a very effectual and convenient anti-acid. It absorbs acids as powerfully as pure alkalies and absorbent earths, without having the causticity of the former, and without oppressing the stomach by its weight, like the latter. Soap is also one of the best antidotes to itop quickly, and with the least inconvenience, the bad effects of acid corrosive poisons, as aqua fortis, corrosive sublimate, &c.

Soap is employed externally for discharging rheumatic pains, arthritic tumours, the humours stagnating after sprains, &c. Some pretend that the indurated tophaceous concretions in arthritic joints, have been resolved by the external use of soapy cataplasms. Several compositions for external purposes are prepared in the shops.

The official preparations of soap are as follow: viz. "Pills of soap with opium," of Lond. Ph.; "Pills of compound squill;" "Aloetic pills" of Ed. Ph.; "Pills of aloes and assafoetida," (See PILLS.) "Pills of aloes and ginger," of the Dub. Ph. are compounded of 1 oz. of hepatic aloes, 1 dr. of ginger-root in powder, $\frac{1}{2}$ oz.

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of soap, and $\frac{1}{2}$ dr. of essential oil of peppermint: let the aloes and ginger be rubbed together to a powder; then add the soap and the oil so as to form a mass. This is an useful pill, and used with advantage for obviating the habitual costiveness of the sedentary, and of leucophlegmatic habits. The dose is from grs. x to grs. xv, or more:—"Soap plaster." (See EMPLASTRUM Saponis, and SOAP PLASTER.) "Cerate of soap," of the Lond. Ph. is composed of 8 oz. of hard soap, 10 oz. of yellow wax, 1 lb. of semivitreous oxyd of lead powdered, a pint of olive-oil, and a gallon of vinegar. Boil the vinegar on the oxyd of lead over a slow fire, stirring diligently till they incorporate; then add the soap, and boil again in a similar manner, until the moisture be entirely evaporated; and, lastly, mix with the oil the wax previously melted. This cerate is occasionally used as a cooling dressing. For the "compound soap liniment" of the Lond. Ph. see LINIMENT. The "Tincture of soap," commonly called "Liniment of soap," of the Ed. Ph., is prepared by digesting 4 oz. of soap sliced in 2 lbs. of alcohol for three days, and then adding 2 oz. of camphor, and $\frac{1}{2}$ oz. of the volatile oil of rosemary, frequently shaking the mixture. These preparations are stimulant and anodyne, and may be beneficially applied against local pains, and in bruises, rubbed upon the parts. "The tincture of soap and opium" of Ed. Ph., commonly called "Anodyne liniment," is made in the same manner, and from the same ingredients as the other tincture of soap, only adding, at the beginning of the process, one ounce of opium. The addition of the opium to the soap liniment renders it, in many cases of rheumatism and local pains, more useful than the simple liniment.

The anodyne balsam, commonly called Bates's balsam, is prepared by digesting two ounces of soap and half an ounce of opium, in a gentle sand-heat, for three days, with eighteen ounces of rectified spirit of wine, and then adding six drachms of camphor and one drachm of oil of rosemary to the strained liquor. This composition, with the addition of opium, is supposed to be more effectual for allaying violent pains than the common opodeldoc: it is also given internally in nervous colics, jaundices, &c.

Soft soap is considerably more acid than the hard soap, and it is, therefore, employed only for some external purposes: a mixture of equal parts of our common soft soap and quicklime is used as a mild caustic. Lewis's Mat. Med. Thomson's Lond. Disp.

SOAP, *Almond*. See SAPO Amygdalinus, and SOAP, *supra*.

SOAP, *Ammoniacal*, a white saponaceous compound, readily made by shaking any oil with liquid ammonia, which is much used medicinally as a stimulating application; but the union between these two is much weaker than between the fixed alkalies and oil, so that this will not harden; and by keeping for some time, the ingredients will partly separate. In order to effect a more intimate union between them, muriated ammonia must be added to common soap.

SOAP-LEES. See LIXIVIUM Saponarium.

The term *soap-lees* is sometimes used technically to denote the "spent ley," which is pumped out of the vat or cistern, after the soap has separated; and which, being more or less alkaline, is reserved either to be used again, or to be evaporated, so that the residue may be calcined for extracting the alkali.

SOAP, *Starkey's*, is a combination of fixed vegetable alkali with essential oil of turpentine. It is so called from its inventor, who combined salt of tartar (carbonate of potash) with this oil, and obtained a saponaceous compound, to

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which many medicinal virtues have been ascribed. It enters also into the composition of pills, named also from Starkey. As fixed alkalies are very difficultly made to unite with essential oils, Starkey found no other expedient for the preparation of his soap, than time and patience. His method consists in putting dry alkali into a matras, and pouring upon it essential oil of turpentine to a height equal to the breadth of two or three fingers: in five or six months part of the alkali and oil will be thus combined together, and form a soap, which must be separated from the mixture, and more of it will be afterwards formed in the same manner. The most commodious method, says Dr. Lewis, of obtaining the combination, is by throwing the salt, red-hot, into a heated mortar, immediately reducing it to powder; then pouring on it, whilst hot, by little at a time, an equal quantity, or more, of the oil, and continuing to grind them together, so as to form a smooth soft mass. Stahl, Rouelle, Beaumé, &c. have published processes for this combination. Mr. Beaumé says, that it may be made in a few hours by triturating, during a long time, alkaline salt upon a porphyry, and adding to this salt, during the trituration, oil of turpentine. This medicine, which has an acrid alkaline taste, and is very apt to deliquate on being exposed to air, was formerly celebrated, under the denomination of soap of tartar, universal corrector, &c. as a diuretic in nephritic complaints, and as a corrector of certain vegetables, particularly of opium: its virtues have not been fully determined by experience, nor does the present practice pay any regard to it.

SOAP, *Volatile*, is of three kinds, viz. one composed of fixed alkalies and volatile oils; another of volatile alkalies and oils of the grosser or more fixed kind; and the third, in which both the alkali and the oil are volatile. Of the first kind is Starkey's soap: those of the second sort are obtained more readily. (See *LINIMENTUM Volatile*, and *EPITHIEM Volatile*.) Combinations of the latter kind, in a liquid form, have been described under *SALTS*; and compositions of the same kinds may be obtained in a solid state, by mixing the salt with the oil, and subliming them together.

SOAP, *Laws relating to*. By 17 Geo. III. c. 52. no person, within the limits of the head office of excise in London, shall be permitted to make any soap, unless he occupy a tenement of 10*l*. a year, and be assessed to, and pay the parish rates; or elsewhere, unless he be assessed to, and pay to church and poor. By 24 Geo. III. c. 41. and 43 Geo. III. c. 69. every soap-maker shall annually take out a licence, for which he shall pay 2*l*. By 43 Geo. III. c. 68. sched. (A), certain duties are laid on soap imported, as therein stated; and upon the exportation of soap made in Great Britain, and which hath paid the duties, the same shall be drawn back, by 43 Geo. III. c. 69. sched. (C): but no drawback shall be allowed on the exportation of foreign soap imported. (27 Geo. II. c. 21.) By 43 Geo. III. c. 69. sched. (A), certain duties are imposed on soap made in Great Britain; and certain allowances shall be made for soap used in the manufactures of Great Britain, sched. (C). Places of making are to be entered on pain of 200*l*. (10 Ann. c. 19. 47 Geo. III. sess. 2. c. 30.) and covers and locks to be provided under a forfeiture of 100*l*. (5 Geo. III. c. 43. 12 Geo. III. c. 40.) The furnace-door of every utensil used in the manufacture of soap shall be locked by the excise officer, as soon as the fire is damped or drawn out, and fastenings provided; and opening or damaging such fastening incurs a penalty of 100*l*. (17 Geo. III. c. 52. 24 Geo. III. c. 48. sess. 2.) Officers are required to enter and survey at all times, by day or night, and the penalty of obstructing is 50*l*; and they

may unlock and examine every copper, &c. between the hours of five in the morning and eleven in the evening, and the penalty of obstructing is 100*l*. No soap-maker shall have any private pipe or conveyance, on pain of 200*l*; and the penalty of obstructing an officer who searches for it is 100*l*. No maker shall have more than one moveable pump, on penalty of 500*l*. Every maker of soap, before he begins any making, if within the bills of mortality, shall give twelve hours, if elsewhere, twenty-four hours' notice, in writing, to the officer, of the time when he intends to begin, on pain of 100*l*. No maker shall remove any soap unremoved, on pain of 20*l*, without giving proper notice of his intention. And if any maker shall conceal any soap or materials, he shall forfeit the same, and also 500*l*. (1 Geo. III. stat. 2. c. 36.) And the penalty of privately making soap is forfeiture of the soap and materials, and 100*l*. (5 Geo. III. c. 43.) Persons assisting in making soap privately shall forfeit, for the first offence, 20*l*; for the second, 40*l*. or be liable to four months' imprisonment till it be paid. (47 Geo. III. sess. 2. c. 30.) Owners or renters of houses where soap shall be privately made forfeit 200*l*. Every barrel of soap shall contain 256 lbs. avoirdupois, half-barrel 128 lbs., firkin 64 lbs., half-firkin 32 lbs., besides the weight or tare of each cask; and all soap, excepting hard cake soap and ball soap, shall be put into such casks and no other, on pain of forfeiture and 5*l*. (10 Ann. c. 19. 12 Ann. st. 2. c. 9.) The maker shall weekly enter in writing at the next office the soap made by him in each week, with the weight and quantity at each boiling, on pain of 50*l*; and within one week after entry clear off the duties, on pain of double duty. (17 Geo. III. c. 52.) Cockets granted for shipping soap to be conveyed to any other part of the kingdom, shall express the quality, quantity, and weight, the mark of the package, by whom made and sold, and where consigned, under penalty of forfeiture and seizure of the same and package. (23 Geo. II. c. 21.) No soap shall be imported, otherwise than in some package, containing at least 224 pounds of hard soap, on pain of seizure and forfeiture, and also package; and the master of the vessel shall forfeit 50*l*. If any person shall knowingly harbour or conceal any soap, unlawfully imported, or reloaded after shipping for exportation upon debenture, he shall forfeit 50*l*. for every hundred weight, together with the goods and package. The maker shall keep just scales and weights, where he makes his soap, and permit and assist the officer to use them, on pain of 10*l*. (10 Ann. c. 19.) And by 10 Geo. III. c. 44. for insufficient scales and weights, he shall forfeit 100*l*.

SOAP-*Ashes*, in *Agriculture*, the refuse of soap-boilers, sometimes termed soapers' ashes. See *ASHES*.

SOAP *Refuse*, the compounds of oil, tallow, and other substances, with lime and pot-ash, which are often met with and used as manures. Most sorts of soapy mixtures are found to have much effect in promoting vegetation.

Soap-suds, or the washings of this sort which are left and thrown away from large mills and manufactories, such as those of the silk and other similar kinds, are found highly beneficial as manures themselves, or for being mixed and blended up with other matters in this intention. The farmers, in some places, collect them by the hoghead, at the rate of from 6*d*. to 1*s*., and mix them up with earthy materials, so as to form rich composts, in consequence of their containing portions of animal matter, gum, and alkali, especially when taken from silk works. And the common soap-suds, which are generally wasted and thrown away, are said to have been found of great utility in cold moist meadows; and would probably be more so, if employed in com-

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bination with rich earthy substances. All the various refuse matters of this sort should be collected, as they are capable

of being used in this way with advantage to the farmer. See *SALINE Manures*.

Solder

SOLDER, **SODDER**, or *Soder*, formed from the French *soudure*, of the Latin *solidare*, *to strengthen*: is a metallic composition, used in foldering or joining together other metals.

For this purpose, it is required that folders melt sooner than the metal to be foldered, that they adhere firmly to its surface, and that they approach as near as may be to the metal foldered in hardness and colour.

The different folders are made of gold, silver, copper, tin, bismuth, and lead; usually observing, that in the composition there be some of the metal to be foldered mixed with some higher and finer metals.

The folder for gold is composed of fine gold, with one-fourth or one-half its weight of fine silver, accurately mixed together by fusion, and afterwards beat out into leaves, somewhat thinner than card-paper, and rendered as soft as

But as this folder does not melt without a considerable degree of heat, it cannot be used when it is inconvenient to heat the work red-hot; and therefore, in this case, copper and brass are foldered with silver.

Though spelter folder be much cheaper than silver folder, yet workmen in many cases prefer the latter. And Mr. Boyle informs us, that he has found it run with so moderate a heat, as not much to endanger the melting of the delicate parts of the work to be foldered; and if well made, this silver folder will lie even upon the ordinary kind itself; and so fill up those little cavities that may chance to be left in the first operation, which is not easily done without a folder more easily fusible than the first made use of. Works Abridged, vol. i. p. 135.

As to iron, it is sufficient that it be heated red-hot, and

as to make the colour of the folder correspond, as nearly as may be, to that of the piece. A mixture of gold and copper is also a folder for fine copper as well as for fine gold.

Gold being particularly disposed to unite with iron, this metal, with a high alloy of copper, proves an excellent folder for the finer kinds of steel instruments.

For larger works in iron and steel, copper, or an alloy composed of equal parts of tin and iron, is employed.

The folder used by plumbers is made of two pounds of lead to one of block-tin. Its goodness is tried by melting it, and pouring the bigness of a crown-piece on a table; for, if good, there will arise little, bright, shining stars in it.

For silver, two kinds of folder, viz. the hard and soft, are used and applied like the gold folder. The hard folder is composed of equal parts of silver and fine brass, and the soft is prepared by fusing the hard folder with $\frac{1}{4}$ th its weight of pure zinc. Another folder for silver may be formed of two parts of fine silver and one part of brass, taking care that these are not long kept in fusion, lest the brass fly off in fumes. For coarser silver, a folder is prepared by melting four parts of fine silver and three of brass, throwing in a little borax, and pouring it out as soon as it is melted.

The folder for copper is made like that of the plumbers; only with copper and tin; and for very nice works, instead of tin, they sometimes use a quantity of silver.

For copper, brass, and the hard alloys of copper, the best hard folder, says Aikin (Dict.), is composed of brass and zinc, in the proportion of from eight to sixteen of the former to one of the latter, according to the required hardness. The soft folder is composed of three parts of zinc and one of lead, and is applied by means of a common foldering iron, made red-hot.

Solder for tin is made of two-thirds of tin and one of lead, or of equal parts of each; but where the work is any thing delicate, as in organ-pipes, where the juncture is scarcely discernible, it is made of one part of bismuth, and three parts of pewter.

The pewterers use a kind of folder made with two parts of tin and one of bismuth: this composition melts with the least heat of any of the folders.

The folder for tin, pewter, and lead (or the plumber's folder), says Aikin (ubi supra), is of two kinds: the least fusible is composed of equal parts of tin and lead; the more fusible contains, besides, bismuth in various proportions. A very good soft folder is prepared by melting together sixteen parts of tin, eight of lead, and four of bismuth.

Spelter folder is made of one part of brass and two of spelter, and is used by the braziers and copper-smiths for foldering brass, copper, and iron. This folder is improved by adding to each ounce of it one pennyweight of silver. But as this folder does not melt without a considerable degree of heat, it cannot be used when it is inconvenient to heat the work red-hot; and therefore, in this case, copper and brass are foldered with silver.

Though spelter folder be much cheaper than silver folder, yet workmen in many cases prefer the latter. And Mr. Boyle informs us, that he has found it run with so moderate a heat, as not much to endanger the melting of the delicate parts of the work to be foldered; and if well made, this silver folder will lie even upon the ordinary kind itself; and so fill up those little cavities that may chance to be left in the first operation, which is not easily done without a folder more easily fusible than the first made use of. Works Abridged, vol. i. p. 135.

As to iron, it is sufficient that it be heated red-hot, and

the two extremities, in this state, be hammered together. By this means they become incorporated one with the other: when it is foldered it is usually done with brass; good tough brass, with borax applied, mixed with water to the consistence of paste.

The duke of Florence's nail, anciently so much admired, as being half iron and half gold, whereas those two metals were deemed irreconcilable, was joined by a kind of folder made by Turneisser, an ingenious chemist of Venice; the secret of which was never discovered till published by Tachenius. This folder is nothing but a little copper, or cyprus vitriol, put between the gold and the iron. For, naturally, the great acidity of the gold reduces the iron into a scoria or rust, when the two are applied over one another; but this inconvenience is removed, by the interposition of a little copper, be it in the smallest quantity imaginable. See the next article.

SOLDERING, or **SODDERING**, among *Mechanics*, the joining and fastening together of two pieces of the same metal, or of two different metals, by the fusion and application of some metallic composition on the extremities of the metals to be joined.

In foldering, some artifice is necessary to make the folder and metals adhere. All the metals, except silver and gold, upon melting, or before, are covered with dross: and all the folders have some of these metals in them: this dross hinders the folder and metal from uniting, and it is necessary to remove it. This is not performed in every kind of foldering by the same materials. The plumbers effect this by greasing the lead, laying on the folder, and melting it with a hot iron, and thus the dross, generated in fusion, unites with the grease, and flows away from the melted metal. The glaziers and tin-men use rosin in powder for the same purpose; for all inflammable substances that will melt are equally conducive to this use. When copper and brass are foldered with pewter, the work is first washed with a solution of sal ammoniac in water, then heated just hot enough to melt the pewter, and the pewter applied to the joint to be foldered. In foldering that requires a greater heat, borax is used.

Thus, in foldering gold, and also silver, take a piece of folder of the proper size and shape, and lay it on the part to be cemented, and sprinkle it over with pulverized borax; then apply the flame of a blow-pipe, which will cause both the borax and folder to fuse, the latter incorporating with, and adhering firmly to, the gold. When the juncture is complete, the piece is left to cool, and the borax is removed by boiling water, or, what is still better, a little dilute sulphuric or muriatic acid. It is observed, that the folder will, in this case, appear considerably paler than the other part, both on account of the silver with which it is alloyed, and of the borax, which always lowers the colour of the gold. This defect, however, may be remedied by melting on the surface of the folder a mixture of two parts of nitre and one of burnt alum, and afterwards washing it off with a soft brush and hot water; by which the natural colour of the gold will be restored, and even heightened. Others direct this operation to be performed by joining together the pieces proposed to be united with fine soft iron wire, and touching the joint to be foldered with a camel's hair pencil, dipped in borax finely powdered, and well moistened with water; and then placing a little folder upon the joint, and applying upon it a large piece of charcoal, and, with a blow-pipe and lamp, blowing upon it through the flame, until it melts the folder; and thus the work is finished. In order to cleanse silver or gold, after it is foldered, make it just red-hot, and let it cool; then boil it in alum-water, in

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an earthen vessel, and it will be as clean as when new. If it be gold, boil it in urine and sal ammoniac.

For a method of soldering, particularly useful to optical

and mathematical instrument-makers, see *GRINDING of Metallic Specula*.

Spinning

SPINNING, the art of combining animal or vegetable fibres into threads or cords, by twisting them together. Wool, silk, cotton, flax, and hemp, are the matters most

wetted during the operation of spinning, to render them more supple; but cotton, wool, and silk, are spun in a dry state.

commonly employed for spinning into threads; and of these, most of the vegetable fibres, except cotton, require to be

The machines employed for spinning are of very different

kinds, and adapted to the materials to be operated upon ; but they have all a spindle, revolving with a rapid motion, to twist the fibres which are attached to the end of it, and are supplied in a regular quantity, as fast as the twisting motion of the spindle will form them into a thread ; and there is also some provision of a bobbin upon the spindle, to take up and retain the thread when made.

The most ancient mode of spinning is by the spindle and distaff, and this method is the simplest of all others. The spindle is nothing more than a piece of hard wood, made round, and sharp-pointed at one end, so that it can be made to spin upon its point, in the same manner as a child's top : the upper part is reduced to a pin or peg, and it is this part which has the fibres united to it, the lower or enlarged part being only to give sufficient weight to make it spin. The spinner must be seated upon the ground, and after having put the distaff in motion upon its point, by twirling it between the hands, get it up to a rapid motion, by striking it occasionally with the hand, with a motion very similar to that by which a child keeps up the motion of his whipping-top, when he draws the lash of a whip round it.

The flax, or material which is to be spun, after being properly prepared, is lapped round the end of the distaff, which is nothing more than a stick that the spinner holds in the left hand, so as to be conveniently situated to draw off from it a few fibres at a time, with the finger and thumb of the right hand, to form the thread. The upper part of the spindle, which is made smaller, like a pin, has the ends of the fibres which are to form the thread attached to it before it is put in motion. These fibres are drawn out of the bunch which is wound upon the distaff, and held between the finger and thumb, so as to be in the direction of the length of the spindle ; therefore, when the spindle is once made to revolve, it twists these fibres together, to form a thread, and as fast as the thread forms, the spinner draws off more flax from the distaff, and guides the fibres between the finger and thumb, so that they shall be regularly delivered out, and make an even thread. The motion of the spindle is constantly kept up, by striking it as often as the hand can be spared from the operation of guiding the thread. When by these means as great a length of thread is formed as is convenient to reach from the end of it to the spindle, the thread is wound upon the outside of the small part or pin of the spindle, for which purpose the spinner applies the fore-finger against the thread, close to the end of the spindle, and bends the thread at that part, so that it will be at right angles with the direction of the spindle, instead of being nearly in the direction of its length ; and also, that it will be guided opposite to the middle of the pin, or small part of the spindle, instead of being at the extreme end thereof. In this situation the motion of the spindle, which is continually kept up, occasions the thread to wind up, or lap upon the pin of the spindle, instead of twisting round upon itself, as in the former case ; but when nearly all the length of thread is thus disposed of, the finger is removed from the thread, and it immediately assumes its original direction, by slipping to the extreme end of the spindle, so as to be twisted round itself by the motion of the spindle, and more fibres are now supplied to it from the bunch upon the distaff, to form a fresh length of thread. In this manner the spinning proceeds, until as much thread is spun and wound upon the pin of the spindle as will make a moderate sized ball.

This simple and inconvenient method of spinning becomes very efficient, when the spindle, instead of being spun upon the ground, is mounted in a proper frame, and turned by a wheel

and band ; this forms a machine which is called the one-thread wheel, and is still used in the country for spinning wool : the spindle is made of iron, and placed horizontally, so that it can revolve freely ; and the extremity of the spindle, to which the thread is applied, projects beyond the support.

The wheel which turns it is placed at one side, the pivots of both being supported in upright pieces, rising up from a sort of stool. The spinner puts the wheel in rapid motion by its handle, and its weight is sufficient to continue the motion for some seconds ; then walking backwards from the spindle, in the direction of its length, she supplies the fibres regularly, and the motion twists them into a thread ; but when a convenient length is spun, the spinner steps on one side, and reaches out that arm which holds the end of the thread, so as to alter the direction of the thread, and bring it nearly perpendicular to the length of the spindle, which motion gathers or winds up the thread upon the middle of the projecting part of the spindle. This being done, she holds the thread in the direction of the spindle, so that it will receive twist, and retreats again to spin a fresh length of thread. For spinning wool, it is not wound round the distaff the same as flax, but the spinner holds a lock of it, doubled over the fore-finger, and draws away the fibres from the middle part of the lock, to do which with regularity is the great art of spinning by hand.

A spinning-machine more perfect than this is the one-thread flax-wheel, with spindle and flyer ; it has the property of constantly drawing up the thread as fast as it is spun, instead of spinning a length, and then winding it upon the spindle. For this purpose the spindle is made longer than the other, and is turned by a band and wheel ; but the wheel receives motion from the foot by a small treadle, because the spinner sits before the wheel to work the spindle, which is supported upon its two extreme ends, and near one end the flyer is fixed ; this is a piece of wood curved to an arc, the vertex of which is fixed on the spindle, and from the extremities of the arc two arms proceed, so as to be parallel to the spindle, and at such a distance from it as to admit a wooden bobbin to be fitted loosely upon the spindle ; and at the same time the arms of the flyer can revolve round the bobbin without touching it. The end of the thread is fastened to the bobbin, and conducted through a hook fixed in the flyer, so that it proceeds from the circumference of the bobbin to this hook, in a direction perpendicular to the bobbin, but turns round the hook so as to come into the direction of the spindle. The thread is then conducted through a perforation made in the centre of the end of the spindle or pivot, upon which it revolves, and to this end of the thread the fibres are supplied. The twisting motion given by the revolution of the spindle forms them into a continuation of the thread, which is gathered up upon the bobbin as fast as the spinner lets it go through her fingers, by a tendency which the bobbin has to turn slowly, at the same time that the flyer to which the thread is hooked is revolving rapidly round the bobbin. For this purpose a string is passed round a small neck upon the bobbin, and one end of the string being fastened to the frame, the other has a small weight to draw it tight round the neck of the bobbin, and occasion friction. In other spinning-wheels, a second band from the great wheel is made to turn the bobbin more slowly than the spindle. The thread which passes over the hook of the flyer is rapidly carried round the circumference of the bobbin ; but as the bobbin follows the motion of the flyer, it only winds up as much thread upon the bobbin as the difference of the two motions ;

and this tendency to wind up can be increased or diminished at pleasure, by the friction which is occasioned by the string or band which passes round the neck of the bobbin. When the winding-up of the thread upon the bobbin has accumulated a ridge of thread upon it opposite to the hook in the flyer, the thread must be shifted to another hook opposite to a different part of the bobbin, for which purpose the arms of the flyer are furnished with different hooks, and this must be repeated several times, until the whole length of the bobbin is filled; it is then taken off to be reeled, and replaced by another empty bobbin.

An improvement was made in the spinning-wheel by Mr. Antis some years ago, which was an application of what Sir Richard Arkwright had before invented. The object is to obviate the necessity of stopping the wheel to remove the thread from one hook to another, in the manner just described. For this purpose, the bobbin is made to move regularly backwards and forwards upon the spindle a space equal to its length, so that every part will, in succession, be presented opposite the hook over which the thread passes, and thus receive the thread regularly upon the whole length of the bobbin. The additional parts necessary for producing this movement are as follow: a pinion of only a single leaf is made to project from the extremity of the pivot of the great wheel, or a worm or endless screw formed on the end pivot, will answer the same purpose, which is to actuate a wheel of seven inches diameter, and ninety-seven teeth; therefore ninety-seven revolutions of the great wheel will produce one revolution of this smaller wheel; upon the face of which a circular ring of wire is fixed, and supported from the wheel by six legs, so as to be oblique to the plane of the wheel, as it touches it at one part, and at the opposite side of the ring projects nearly three-fourths of an inch. This ring of wire gives motion to an upright lever, about fifteen inches long, and moving on a centre at three inches from its lower extremity, where it has a pin fixed in it, and resting against the oblique ring of wire; therefore, when the wheel turns round, it communicates a small motion to the lever, in consequence of its obliquity to the plane in which it revolves. The upper end of the lever is connected to an horizontal sliding-bar, situated beneath the spindle, and having an upright piece of brass, which works in the notch of a pulley, formed on the end of the bobbin, and drives the bobbin backwards and forwards upon the spindle, according as the oblique ring of wire forces the pin at the lower end of the lever in or out, when the wheel moves round. To regulate and return this alternate motion, a small weight hangs by a line to the sliding-bar, and, passing over a pulley, rises and falls as the bobbin recedes and advances, and tends constantly to keep the pin at the lower end of the lever in contact with the wire. It is evident, from this description, that one staple only is wanted to the arms of the flyer, which being placed near the extremity, the thread passes through it, and by the motion of the bobbin, is laid regularly upon it from one end to the other.

The invention has also another advantage over the old method, which always winds the thread in ridges upon the bobbin; and if the thread breaks in reeling the yarn, the whole bobbin may as well be thrown away, because the thread cannot easily be found again; but this improved wheel always winds the threads across upon one another, by which means the end can never be lost.

In order to regulate the friction on the bobbin, and retard its motion in a greater or less degree at pleasure, there is a neck of brass or steel fastened to one end of it, and embraced by a kind of small vice, or pincers, fixed to the

sliding-bar. This vice must be made either with two elastic springs with wooden tops, or of wood wholly, and faced with leather; but if made of wood only, then a spring must be made beneath the shoulder of the screw, to answer the same purpose. By tightening this screw more or less, the friction on the bobbin may be regulated to the greatest nicety, provided the springs are of a strength rightly proportioned to their functions. It will readily appear, that all this may be done without the least effect on the velocity of the whole machine, as thereby nothing is added to the general friction so as to obstruct it.

It was not until the latter end of the last century, that spinning-machines of greater powers were constructed; but all threads were spun by one of the machines which we have described; the first being used for cotton and wool, and the other, with the bobbin and flyer, for flax; but for very coarse threads, two spindles were applied to the latter machine, and the spinner having the wool wound round a band, tied it round her waist, instead of winding it upon a distaff, and was thus able to draw out fibres with each hand, and supply two spindles. And of the other simple spindles, several were made to turn together by the movement of one large horizontal wheel, around which the spindles were arranged in directions radiating from the centre, and each spindle received a rapid motion by the contact of the edge of the large wheel, which was turned round by one person. The spinners each stood opposite to his respective spindle, so as altogether to occupy a large apartment, and by this means they could do much more work than formerly, having none of the interruptions of turning the wheel.

The first improvement of any importance in spinning, was that of the spinning-jenny, invented by Hargraves, as related in our article COTTON; and the machine itself will be described under the article WOOLLEN *Manufacture*. This machine consists of a number of spindles, similar to those of the one-thread wheel, which are all mounted, in a perpendicular direction in the same frame, and turned round by one large wheel, situated in an horizontal direction, and put in motion by a crank at the upper end of its spindle. The threads from each spindle are conducted nearly in an horizontal direction, but being quite at the point or upper extremity of the spindles, do not wind upon the spindles, but will receive twist, because the threads slip over the top of the spindles as they revolve. The threads are guided between two rulers of wood, called the *claspers*, instead of the finger and thumb of the spinner. These rulers are made to fit together, so as to hold the fibres between them, and are fitted up with wheels at the end to run upon the frame, and thus advance or retreat at pleasure from the spindles. It was not attempted with this machine to spin a finished thread immediately from the lock of wool or cotton, but coarse and loose threads are previously prepared on the hand-wheel, which can be done with great rapidity, and the coppius or balls of these loose threads are placed in the jenny, and conducted, first between the claspers or rulers before mentioned, and then to the spindles. By this means, when the carriage of the claspers is drawn backwards from the spindles, the claspers being separate, the threads draw between them from off the coppius, and at the same time that portion of each thread which is between the claspers and the ends of the spindles, receives its twist; but having drawn out a certain length of each thread in this manner, the claspers are shut together; and the motion of the spindles, as also the retreat of the claspers, is continued, by which means the threads are stretched out to their intended fineness, and being thus finished, the threads are wound upon the spindles, by being brought opposite to the middle part

of the spindles by a rail of wood, called the *faller*, which moves upon centres, so as to descend horizontally before all the spindles, and depress all the threads together, so that they will wind up by the motion of the spindles, and as they wind, the clasps return towards the spindles. The operations are then again repeated, and thus continued, until the coppins or balls of thread, wound upon the spindles, acquire their proper size.

The next improvement in spinning-machines was the introduction of the slubbing-machine, or billy, for preparing the rovings for the jenny; an operation which was at first performed by the hand-wheel. This machine has similar parts to the jenny, but they are differently arranged, to adapt it to spin the wool as it comes from the carding-machine, in the state of cardings, which are locks of wool drawn out to about the size of candles, and from two to three feet in length. For this purpose the spindles are made to travel on the carriage, and the clasps stand still, being the reverse of the jenny. The cardings are laid upon an endless cloth, which revolves over two rollers, and lies in an inclined position at the end of the machine; and one carding is laid upon the cloth opposite to each spindle, the ends being pieced with fresh cardings by children, as fast as the spindle works them up. A roller presses down upon the cardings, to hold them fast upon the feeding-cloth, and to make them move with it; and just beyond this roller the clasps are fixed to hold the rovings, when the proper lengths are drawn out by the retreating of the spindles, which, as before stated, are situated in the carriage. The operation of the billy is the same as that of the jenny, *viz.* that the carriage is drawn out, and the feeding-cloth revolves over its roller to give out the cardings until a certain length: the clasp is then shut down, and the further extension of the threads is produced by stretching; which being done, the threads are wound upon the spindles.

The inventions of sir Richard Arkwright soon superseded these machines. His principal invention in the spinning was the introduction of the rollers, to draw out or extend the fibres to their full length, which is by this means much more perfectly performed than by the fingers of the spinner. For the immediate twisting of the thread, he adopted the spindle, bobbin, and flyer of the old flax-wheel, placed in a vertical position, but added to it the important improvement of raising and lowering the bobbin, to distribute the thread regularly and equally upon all the length of it, the same which we have before described as being applied by Mr. Antis to the common spinning-wheel. A full description of this machine, which is called the water spinning-frame, will be found in the article *COTTON MANUFACTURE*, Plate IX. *Cotton Manufacture*.

The spinning-jenny was again introduced, and rendered equal, and for some purposes superior, to the water-frame, by Mr. Crompton, who combined with it the system of rollers of sir Richard Arkwright, and called it the mule. It is also fully described under Plate XI. *Cotton Manufacture*. See *COTTON MANUFACTURE*.

The great success which attended the spinning of cotton by these machines, induced many persons to attempt the spinning of flax and wool by similar means. Short wool, for the manufacture of cloth, is spun by the billy and jenny; but flax and long wool for worsted require very different treatment from cotton and short wool, particularly the flax, owing to the great length of the fibres, and to their being of such irregular lengths: in consequence, when they are extended by the rollers, on Arkwright's principle, some fibres will be broken, if the distances between the rollers is too small; and on the other hand, if the distance is too

great, the fibres will not be properly extended. The latter, however, is the least evil of the two; and, in consequence, the spinning-frames for flax have the rollers, between which the extension or drawing out is effected, placed at a distance of from 14 to 18 inches between the first two pair of rollers, through which the flax passes; the next two pair six or eight inches; after which it is passed between the third pair of rollers at a distance of five or six inches, and then delivered to the spindles, which are similar to those of the water-frame, but placed in an inclined position. The rollers are made in a very different manner from those for cotton, being only narrow wheels just wide enough to receive the fibres of flax between them; and the fibres are prevented from getting out sideways by small tin spouts, through which the flax passes, as the rollers draw it forwards. The reason of this is, that the flinty surface of the flax would soon wear a hollow part round a plain roller, which would then let the flax slip through; but the narrow wheel wears down equally over the whole breadth of its edge. The lower pair of these rollers, or wheels, revolves in a small trough of water, in the same manner as a grindstone, and thus keeps the flax constantly wet, which is necessary, in order to soften the fibres, and make them spin into a firm and smooth thread.

Worsted is also spun in a frame resembling the water-frame of Arkwright, from which it only differs in the relative distances of the rollers, by which the drawing out or extending of the fibres is effected.

Messrs. Clarke and Bugby obtained a patent in 1806, for improvements in a machine for spinning hemp and flax, which is intended to be worked by hand labour, and to be at such a small expence, as to bring it within the reach of small manufacturers. The inventors state it to be constructed upon such safe and easy principles, that no length of experience is necessary to enable children to work it; and that it occupies so little space, that the machines may be placed in small rooms, out-buildings, or other cheap places. To effect the above purposes, it was necessary to get rid of the flyer fixed upon the spindle used in the old machinery for spinning hemp or flax, which additions require a power in proportion of five to one; and also to surmount the difficulty which arises from the want of elasticity in these substances, and which prevents them from being spun, by stretching out at the same time that the thread is twisted, in the manner of the mule or jenny.

These patentees recommend a machine, which is in fact a mule with certain modifications; and to give the effect of elasticity in the fibres, they have two methods. The most simple, and that which they particularly recommend, is to provide a holder of large wire for every spindle, which holders are several inches in length, fixed in an arbor or shaft, that extends from one end of the carriage to the other.

This arbor or shaft, with the holders, may be considered as an enlarged and improved substitute for what is called the faller in the mules or jennies for spinning cotton, and the wire-holders fixed therein have elliptical eyes at their extremities, through each of which a thread is conducted in its passage from the rollers which draw out the thread to its spindle. The wire of which the holder is made, after forming the elliptical eye, is left or extended beyond the uppermost part, something in the manner of a cork-screw, so that the yarn may be conveniently slipped in when occasion may require it. These holders for each thread are for the purpose of keeping the yarn in a state nearly vertical over the tops of the spindle, when the carriage which contains them is coming out; and as they will readily yield or spring from the vertical position, they have the same effect as elasticity

in the fibres of the substance which is to be stretched out ; but the wires being removed from the vertical situation at the beginning of the return of the carriage, and thrown into nearly a horizontal position, by inclining the shaft into which they are all fixed, they bring the yarn below the tops of the bobbins or quills which are fixed upon the spindles, which will then wind up the threads upon them when the spindles are turned round, and then the wire-eyes being regularly curved, and raised up again by the motion of an elliptic wheel, which is turned round by the machine, they distribute the yarn regularly upon the bobbins or quills, and prevent it from hinkling, and improperly doubling or twisting together. Another method of compensating for the want of elasticity in hemp and flax, is to fix a round bar of wood, about an inch and a half in diameter, the whole length of the carriage, about three or four inches above the tops of the spindles, so that the outer surface, or that next the person who works the machine, may be perpendicular, or nearly so, over the tops of the spindles, the inner side having pieces of wood or metal fixed or nailed thereto, leaving only small spaces or notches between each, for the yarn to pass through. The use of these pieces is to prevent the threads from getting together and entangling. Every thing relating to the wire-holders before mentioned, and the arbor to which they are affixed, must be applied in concert with these pieces of metal, which form a separation between the threads.

The art of spinning, which nature has given to many animals of different kinds for their preservation, and other purposes, is not confined to the inhabitants of the earth or air alone, but is even extended to those of the sea. M.

Reaumur has shewn, by a series of curious experiments, that the common muscle, and some other shell-fish of the sea, possess it in a great degree of perfection. See *MUSCLE*.

But he observes, that though the workmanship is the same, the manner of producing it is very different. Spiders, caterpillars, and the like, make threads of any length that they please, by making the viscous liquor, of which they are formed, pass through a fine perforation in the organ appointed for this spinning : but the way in which the muscles form their threads is very different, as the former resembles the work of the wire-drawer, so does this that of the founder, who casts metals in a mould. The canal of the organ destined for the muscle's spinning, which, from its shape, is commonly called its tongue, is the mould in which its thread is cast, and gives it its determinate length. *Mem. Acad. Par. 1711.*

SPINNING-Wheel, in *Rope-making*, for twelve spinners to spin yarn at the same time, is about five feet in diameter, and is hung between two posts fixed in the ground : on its top is fixed a semi-circular frame, called the head, which contains twelve whirls, that turn on iron spindles, with hooks to their front ends to hang the hemp on, and are worked by means of a leather band encircling the wheel and whirls. The whirls are made to run with a truer motion when the head on the rising side of the band has a larger segment of a circle than the falling side ; or in other words, let the base part of the head be longer from the middle than the opposite or falling side, by which means the band will be kept equally tight over the whirls, and consequently the motion be alike to all. N.B. Heads made in this manner have the wheel turned always the same way.

Spirits

SPIRITS, *Distilled*, a general name given among distillers to those ardent liquors that are obtained from various materials, and by different processes of distillation. The nature and properties of these liquors, and the modes of obtaining them, are detailed under the articles ALCOHOL, BRANDY, DISTILLATION, FERMENTATION, &c.; but we shall here specify some particulars that more immediately relate to the common spirituous liquors that are, we lament to say it, so much in use in our own country. These are, for the most part, prepared from fermented corn of one kind or other, with certain additions, at the pleasure of the distiller, of molasses, carrots, and other sublaccharine vegetables. The principal ingredient, except in a season of scarcity, is one kind or other of grain. (See ADDITION.) The spirit thus procured is rectified for sale by being redistilled with juniper-berries, turpentine, and other substances, in order to modify and improve its flavour and appearance. The grain, when barley is used, is usually first malted, and in Scotland it is dried with peat, which gives to the spirit distilled from it, called "whisky," its peculiar flavour.

It is then ground into coarse powder, and the infusion fermented with yeast in large tuns. This fermented liquor is called "wash," and in this state it is fit for distillation. Under the articles already referred to, the general process and the implements used in it are described; but previously to the operation some substances are added to the wash, for the purpose either of increasing the quantity of spirit that is afforded by it, or of keeping down the essential oil derived from the malt, which would give the liquor a nauseous flavour, or of regulating the boiling within the still, and preventing it from boiling over or "running foul," or of neutralizing the acid generated during the fermentation, which would very considerably lessen the product of spirit. For these purposes soap is considered the best addition, and accordingly it is used in large quantities. Other distillers use alkalies. At the commencement of the operation, the liquid is oily and turbid, and has a nauseous flavour, on account of the oil of the malt which accompanies it; but by degrees it becomes clear, and runs so to the last, although its strength decreases, and it becomes more watery,

and consequently of less specific gravity. (See *Specific Gravity*.) The quantity intermediately obtained, omitting the first and the last products, is then redistilled or "rectified," (see *RECTIFICATION*); and in this stage of the operation, those additions (such as juniper-berries, &c.) which give the spirit its flavour, are introduced into it. The process of distillation on a small scale is simple and easily conducted; but the large distilleries, where expensive works are carried on, require a greater degree of practical skill, both in the preparation of the apparatus, the adjustment of the materials, and the conduct of the operation. In order to expedite the process, several alterations have been made in the form of the still, particularly in Scotland, where it is an object of importance to be quick in the dispatch of the operation, on account of the mode of levying the duty; and, therefore, by gradually widening the bottom and contracting the height of the still, distillation is performed with a surprising rapidity. A still is said to have been constructed, which contains only 40 gallons in the body and three in the head, and in the use of it the whole time of its operation, from its commencement to its close, amounts only to $2\frac{1}{2}$ minutes, when the charge of wash is 16 gallons, or $\frac{2}{3}$ ths of the whole content. In rectification, which is a slower process, the charge is 24 gallons, and the time of distilling about 10 minutes.

A good spirit may be obtained without malting the grain, whether it be barley, or any other kind of corn which will answer the purpose. With us, a mixture of barley and malt is generally preferred; in Holland, the very best geneva is made from wheat and malt, though more commonly from malt and rye, the latter yielding more spirit than wheat.

The following process is that which is practised by most distillers. A quantity of rye-flour, coarsely ground, is mixed with a third or fourth part of malt, and put into the fermenting tub, with cold water, stirring it well with the hand, to prevent the meal from clotting. Water of a blood-warmth is then added, in sufficient quantity, after which the ferment, composed of the yeast of former operations, dried and kept for a certain time, is mixed with the whole. (See *FERMENT*.) When the weather is favourable, and the heat well regulated, the fermentation begins in six hours, and terminates on the third day, when the liquor becomes transparent, and assumes a hot pungent taste. The distillation is then immediately commenced, before the liquor turns sour, which should as much as possible be avoided. The distillation is conducted very slowly, to prevent the impregnation of the oil of the grain with the spirit, and of course the unpleasant flavour of the spirits. The first spirit is then rectified by a second distillation over juniper-berries, or in "double geneva," by a third process.

In some of the ordinary sorts, however, the juniper-berries are mixed with the fermenting materials, and one distillation suffices. In the common geneva or gin, vulgarly used in this country, the fine juniper flavour is coarsely imitated by turpentine. See *GENEVA*.

For the process of obtaining arrack, brandy, and rum, see *ARAC*, *BRANDY*, and *RUM*.

SPIRITS, *Proof*, or *common saleable goods*, are spirits of any kind of a determinate strength, being the same with those of good brandy, and the malt and sugar spirits of the distillery, as they are usually sold; containing equal quantities, or definite proportions, of rectified spirit and water.

The best proof spirit is that distilled from French wine; but for common use, the spirit drawn from molasses may be employed.

The common method of examining whether spirits have this due degree of strength is this:—take a long phial, fill it

half way with the common malt spirit, and give it a smart stroke by its bottom against the palm of the hand, there will then appear on the surface a chaplet, or crown of bubbles, which will go off again in a strong manner; that is, first remaining a while, and then going off by degrees, without breaking into smaller bubbles, or swelling into larger.

By this experiment all the traders in spirits judge of the strength of the goods they purchase; yet this is a mere fallacy and deception; for if only a little vinous or saccharine matter, as treacle, syrup, must, rob of fruits, or the like, be added to a quantity of highly rectified spirit of wine, this slight addition will give a brandy proof to that spirit. See *ALCOHOL*, *BRANDY*, and *BEAD Proof*.

Whether there be any secret for making weaker spirits shew this proof as well as brandies, &c. is not certainly known; but the thing is practicable, since arrack, which is but of half the strength of brandy, gives as fair a proof this way; and if a drop or two of any essential oil be added to a pint of brandy, it takes off its proof, and makes it appear much weaker than it is. The true strength may, however, always be known, by carefully burning away a measured quantity of brandy, &c. since if it leaves one half water it is right; if more or less, it is too strong, or too weak.

But beside the false method of judging of brandies by what is called *proof*, there is another not less fallacious one of judging of their goodness, though kept as a great secret in the hands of some dealers, and imagined a certain criterion to determine whether foreign brandies are mixed with corn spirits. These distillers are provided with a certain yellow liquor, a few drops of which being poured into a glass of right French brandy gives it a beautiful blue colour, and, by the strength and goodness of this colour, they judge and buy; but if common malt spirit be tinged with oak, it would give this colour equally with French brandy, and might be purchased as such. This proof tincture is expeditiously made, by dissolving a little green vitriol, first calcined to a redness, in a weak spirit of sea-salt, which thus becomes a yellow liquor, a single drop or two of which being added to a glass of any inflammable spirit, coloured yellow or brown with oak, or with long remaining in the cask, will instantly turn it of a bright and beautiful blue.

The best way of judging in these cases is by the nose and palate. Dilute a quantity of brandy considerably with water, and you will perceive the malt taste, if mixed with malt spirits; or burn a little in a spoon, and by the smell and taste of the water it leaves, you will easily judge whether there be malt in it.

Proof spirits may be distinguished into three kinds, *perfect proof*, *more than perfect proof*, and *less than perfect proof*. By *perfect proof* is usually understood that crown of bubbles, before mentioned, of a certain size, arising as a head upon a small quantity of a well-qualified spirit shook in a slender phial.

Proof more than perfect, is that in which the bubbles raised by shaking the spirits, are larger than those on the common or perfect proof, and go off more suddenly; that is, according as the spirit is higher, or approaches more to the nature of rectified spirit, or, as it is usually called, *spirit of wine*.

Proof less than perfect, is that in which the bubbles are smaller, and go off quicker and fainter than in perfect proof; the spirit in this case being mixed with more than its own quantity of phlegm, or being too poor for sale.

The surest method of judging of the strength of spirits, is by the hydrometer, water-weigh, or balance; or, 2dly, by distillation, or finally, by deflagration. The specific gravity of totally inflammable spirit is so much less than that of

phlegm, or common water, that it is easily sensible upon the balance; whence an exact hydrometer, well balanced and graduated, and furnished with a proper scale of weights, may be of great use to assign the proportions in which pure spirit and water are mixed in any given liquor. (See *SPECIFIC GRAVITY*, and *HYDROMETER*.) Though, perhaps, a readier way than this may be that of M. Homberg's, mentioned in the Memoirs of the Paris Academy, 1718, for determining the different gravities of different fluids, by means of a bottle with a very long and slender neck; which being filled to a certain height with any mixture of spirit, is weighed against the same bottle filled with pure water.

The most exact of all methods of determining the strength and spirit is by distillation, rectifying it up to an alcohol, or totally inflammable spirit; but this, though liable to no error, is too tedious to come into common use. And, upon the whole, the best method of all others, seems to be that of deflagration, which M. Geoffroy has been at much pains to adjust and improve.

In commerce, with regard to spirits, it would certainly be a much better method to abolish such uncertain proofs, and to make all the goods of the strength of what we call spirits of wine; that is, a totally inflammable spirit, whose purity is much greater, whose strength may always be found out with exactness, and whose bulk, stowage, carriage, and incumbrance, would be only half in regard to that of brandy, or proof spirits; and it might at all times, as occasion called for it, be mixed into a great variety of extemporaneous liquors, and the exact degree of strength would be always precisely known.

This operation, indeed, in the common way, proves so tedious and expensive, and, after all, so short of expectation, and so generally unsatisfactory, that it is not to be expected that the common distillers, till they have fallen into a better manner of working, should come into the proposal. But if, instead of the common way of rectifying by the hot-bill, they would try the use of a large *balneum Mariæ*, made of a large rectangular boiler, and a set of tall conical vessels, they will find that little fire, and little attendance, and consequently very little expence, will, in this manner, furnish them with spirits reduced at once to this standard, and greatly superior, in all respects, to the common ones of the same strength. In this case there would be no need of any addition of salts; but the distiller may work more perfectly, and more expeditiously without them, and thus preserve the fine essential vinosity of the spirit, which, in the common way of working, they constantly lose.

The advantage of this method would be yet greater to the apothecaries, and the makers of compound cordial waters, who want only a pure spirit of such a strength, and suffer greatly in the fineness and perfection of their commodities, by the spirit they are obliged to use having in it a fulsome and nauseous oil of its own, which will always mix itself with their compositions, and the oils of the aromatics, &c. which they add to it. If spirits were brought to this standard for the market, there would be no possibility of deceit, and no farther examination need be made of it by the buyer than its burning perfectly dry in a spoon. Shaw's Essay on Distillery.

It is, however, to be observed, that though the burning of spirits away in a spoon may serve the trader in the common way, yet M. Geoffroy has observed, that they are no proofs for the philosopher, or the chemist, being not at all determinate or exact, though commonly supposed so.

From what has been said, it appears that brandy is much more inflammable than wine, and spirit of wine much more so than brandy, and ought to burn away without leaving

any remainder. Hence it is vulgarly supposed, that such spirit of wine as burns wholly away contains no phlegm, and that if two parcels of spirit both burn wholly away in this manner, they must be the same in strength, and in all other qualities; but M. Geoffroy has proved by experiment, that such spirit as burns wholly away, does yet contain a great deal of water, and two parcels both may burn thus away, and yet be very different; and that this trial is not determined by the entire absence of the phlegm, but by its proportion to the oil.

If the same spirit of wine, which in the common way of burning leaves no water, be again tried, by burning it in a hollow vessel set to float in a large quantity of cold water, it will then leave a considerable quantity of water; nay, all that is rectified only in the common way, leaves a large portion of phlegm on this experiment. The plain reason of which is, that this is the only fair trial, the other in the common way being fallacious. In this there is no more water left than was in the spirit; but in the other, the vessel becoming heated by the burning of the spirit, that heat gradually evaporates the water, as the spirit burns away; so that the one is as soon gone as the other. But keeping the vessel cool by external water, prevents that evaporation, and consequently retains and discovers all that cannot burn of the spirit.

The quantity of water thus discovered in spirit of wine is very great, and it has always been found, that in proportion as the experiment has been made more and more perfect, the spirit has always appeared proportionably less and less so.

Pure alcohol, or alcohol of a specific gravity of .796, at 60° Fahr., which is the strongest that can be procured, leaves no water; rectified spirit of moderate strength, 25 per cent.; French brandy, 56; and common malt liquor, 65.

The test for ascertaining the strength of spirits by pouring a few drops on gunpowder, is very incorrect. A more accurate test than any of these, and sufficient for common purposes, is to shake the spirit in a phial with very dry carbonate of potash, and observe the quantity of water attracted by the alkali, which indicates its strength. But the only certain mode of ascertaining the relative strength of spirits, is by determining the specific gravity of the spirit at a given temperature; thus, at 60° Fahr. the specific gravity of rectified spirit is .83599, at 65° it is .83362, and at 70° the gravity of the same spirit is .83134; while the gravity of the proof spirit of the London College, at the same degree of temperature, is .93002, .92794, and .9258, (see the table under SPIRITS, in the *Materia Medica*.) the weakest spirit having the greatest specific gravity, and this diminishing as the temperature increases. For ordinary purposes, the relative strength of spirits may be known by weighing the sample to be tried in a phial capable of holding exactly 500 grains of water. An equal bulk of rectified spirit weighs 418 grains, and of proof spirit 465; hence the number of grains above or below these sums will indicate the relative strength of the spirit.

The quality of the phlegm that is left is also of use to judge of the spirit by; if that were perfectly fine, thus ought to be perfectly limpid and clear, and without taste or smell: as it wants either of these properties, it is a proof of the want of perfection of the spirit it is obtained from; but the greatest of all defects, is its having a coarse oil swimming upon it, and giving the colours of the rainbow in different lights. Mem. Acad. Par. 1718. See BRANDY.

SPIRITS, *Colouring of*, the art of giving to distilled liquors a colour, which takes off their watery appearance, and gives them a resemblance of the foreign brandies, &c.

The colouring is not only necessary on this account, but as we usually esteem the spirits by the proof of the crown of bubbles, it is found that the clean rectified spirit will not afford this proof till it has received its dose of the colour. The distillers dispense this colour in any proportion that they find convenient or necessary; it is always yellow, but, according to the degree, differs extremely in deepness, from the palest straw-colour to the deepest orange. This art of colouring was first introduced, from observing that all the fine and soft foreign brandies, that had the mellowness necessary to their perfection to the taste, had also a yellow colour. The colour, in this case, has indeed nothing to do with the flavour; but that being kept in casks the same age that was necessary to give them this mellowness, would also give them a colour from the wood. It was hence supposed, that the particular excellence of the foreign brandies depended on the woody colour, and accordingly pains have been taken to give the same colour to our spirits by various methods.

The way of obtaining it, by many years standing in the cask, proved too tedious for our hasty workmen, and accordingly they provided means of giving it extempore by strong tinctures of several ingredients; the chief of which are logwood, saffron, Japan earth, treacle, burnt sugar, and oak-chips; the three former of these have but little to recommend them, but the others are found very ready, and very proper for the use.

Treacle gives a fine colour not much unlike that of the foreign brandies, and being necessarily used in a large quantity, as its colour is but dilute, it not only mends the bubble, or bead-proof, impaired by the rectification, but also gives it a fulness in the mouth; both which properties are very agreeable to the vulgar, who are the chief retail consumers of these coarse goods.

Burnt sugar, that is, sugar dissolved in a little water, and scorched over the fire till it turns black, goes much farther in the colouring than treacle, and at the same time gives no sweetness, but rather an agreeable bitterness; and thus recommends itself to the nicer palates, that are not for a luscious spirit. Indeed sugar, thus treated, tinges to a great perfection, and that without loss of time, and with as much cheapness as can well be desired.

The last article mentioned, namely oak-chips, is of all others the most natural for imitating the dye of foreign spirits, as it is the very wood of which the casks they come over in are made, and from which they take that colour of which we are so fond. The colouring with oak has also this farther advantage in spirits meant as sophistications of the foreign ones, that it will stand some tests usually had recourse to on the occasion, which the others will not stand.

Common spirit poured on oak-chips, and digested in a moderate heat, easily fetches out the resinous part of the wood on which the colouring depends; but then it does not go near so far as the burnt sugar; a large quantity of oak being required to colour a small parcel of brandy, or spirits. It is advisable not to make the tincture every time, but to have recourse to an extract of this wood in a liquid form: this extract is best made in two menstrums, alcohol and water, and may be evaporated to any strength, so that a very small dose of it will tinge a great quantity of liquor. The two liquid extracts will be mixed together, and as they will be apt to separate in standing, it will be proper to add to them, when newly made, a quantity of fine sugar; this will give a body to the whole, and it will keep better from mouldiness than it would without it. Shaw's Essay on Distillery.

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SPIRITS, Convertibility of. This is a doctrine that has obtained among many of the most curious experimenters, and, indeed, the most intelligent of our chemists have always allowed, that provided proper care were taken in the getting together of the material, one spirit may always be changed into another, as brandy into rum, malt-spirit into brandy, and brandy into malt-spirit. The principles on which this is believed are these.

All simple spirits (as they are called) consist of four parts, water, oil, phlegm, and alcohol; the last of these is the essential part, and is what constitutes the whole a spirit. In reducing spirits, therefore, to their utmost degree of simplicity and purity, it is evident that the three superfluous parts are to be got rid of, and the fourth left alone; by this means the alcohol is procured distinct, and is a liquor *sui generis* of many peculiar qualities, not to be found in any other fluid.

Among others, it has these remarkable properties:

1. When absolutely purified, it is an uniform and homogeneous liquor, capable of no farther separation, without loss or destruction of some of its homogeneous parts.
2. It is totally inflammable, leaving no foot nor any moisture behind.
3. It has no peculiar taste or flavour, any more than pure water, except what is owing to its nature as alcohol, or perfectly pure spirit.
4. It is an unctuous and crispy fluid, running veiny in the distillation, and its drops rolling on the surface of any other fluid, like pease upon a table, before they unite.
5. It appears to be the essential oil of the body it is obtained from, broken very fine, and intimately and strongly mixed with an aqueous fluid, which is assimilated, or changed in its nature in the operation.
6. And lastly, it seems to be a kind of universal fluid, producible with the same properties from every vegetable subject; but to produce it thus requires some care in the operation. See ALCOHOL.

On these principles is founded the opinion, that all spirits may be reduced to a perfect similarity, or sameness, from whatever subject they were procured, and on this depends their convertibility into one another; for when once they are brought to this standard of simplicity, there needs nothing more than to add the oil of such of the finer spirits as is required to convert the spirit into that particular kind. By this means the same tasteless spirit, whether obtained from malt, sugar, or grapes, may be made either into malt-spirit, brandy, or rum, by adding the essential oil of the grape, sugar, or malt; and thus, what was once malt-spirit, shall become brandy, or whatever else the operator pleases.

Many methods have been attempted to obtain the first point, that is, the reducing of the spirit to perfect and pure alcohol. The most practicable means seem to be long digestion, and the repeated distillation from water into water, where the essential oil will at once be left upon two surfaces, and the acid imbibed. The shorter ways are those by rectifying from neutral absorbent salts and earths; such as sugar, chalk, and the like. And lastly, the use of fixed alkalies may be tried, for these very forcibly keep down both the phlegm and oil; inasmuch that this last method promises to be the shortest of all, if the art were known of utterly abolishing the alkaline flavour, which the alcohol is apt to acquire in this operation, and which, for this purpose, is by no means suitable, as absolutely destroying all vinosity, which universally consists in a fine volatile pungent acidity. The distillers are the only people whose business would lead them to make the experiment. This method of converting one spirit into another, would be of immense

profit to them if they could perfectly succeed in it; but as it would require time and slow processes to bring it about, there is but little hope of its ever being brought to bear among them, while they are in their present scheme of doing every thing with dispatch and hurry.

Dr. Shaw has said a vast deal in the praise of a tasteless spirit, which is producible from a vegetable substance, only overlooked, as he tells us, because it is too common, with which all the foreign spirits might be imitated to the utmost perfection by means of their essential oils, all thin fine wines raised to any due degree of strength, without giving them the brandy flavour, and many other things of great use performed; but he has not told us what the vegetable substance is from which we are to obtain this. Shaw's *Essay on Distillery*.

SPIRIT, *Ardent*, called also *spirit of wine*, because it can only be obtained from substances which have undergone the vinous fermentation, is a very light, very volatile, very fluid liquor, perfectly white and limpid, and of a strong, penetrating, agreeable taste and smell. See ALCOHOL.

Spirits drawn from wine, such as French brandy, may, in a great measure, be purified or rectified by simple distillation, in tall vessels with a gentle heat, the pure spirituous parts rising before the phlegm: if French brandy be thus distilled to one-half, the distilled spirit proves tolerably pure. See BRANDY.

But wine or brandy being in this country too dear an article for distillation, this purification is chiefly practised on the cheaper spirits of molasses and malt-liquors. To separate the offensive oil with which these abound, after they have been freed by distillation from the greatest part of their phlegm, they are mixed with an equal quantity of spring-water, and the spirit drawn off again by a gentle heat: a considerable portion of the oil is thus left behind in the water, which now proves turbid and milky, and very nauseous both in smell and taste. The first produce is the strongest and purest, and when it has come over to the amount of $\frac{1}{4}$ th of the whole contents of the still, forms the rectified spirit. By repeating this ablution with fresh quantities of water, the foulest and most offensive spirits may be purified from all ill flavour. To complete the purification, or free them from their remaining phlegm or oil, or the watery vapour which is raised even by the gentlest heat in which they can be distilled, a little fixed alkaline salt, thoroughly dried and powdered, or lime, or some other article of a like kind, is added; which, imbibing the phlegm, is thereby dissolved into a ponderous liquid, that does not mingle with the spirit, but settles at the bottom. If the spirit is very phlegmatic, four pints will require a pound of the alkali; if the distillation has been performed with due care, half this quantity, or less, will be sufficient: in either case, if all the salt dissolves, the spirit is to be digested with a little more, till at least a part remains undissolved. The spirit now poured off is to be again distilled, in order to separate from it a portion of the salt which has united with it, and which, though extremely minute, may in some respects change its qualities. As some particles of the alkali are apt to be carried up with it, even in the distillation, so as to communicate an ill flavour, or an urinous taste, it is advisable previously to add a small portion of calcined vitriol, or burnt alum and charcoal, which will completely absorb the alkali, without giving any new impregnation to the spirit. Malt-spirits, when properly rectified, yield as pure and as strong rectified spirit as brandy. Lewis's *Mat. Med.* See DISTILLATION, and SPIRITS, in the *Materia Medica*, *infra*.

When only a small quantity of spirit of wine is to be rectified, the usual operation for this purpose, by means of distillations of the spirit called aqua vite, obtained from the first distillations of liquors that have undergone the spirituous fermentation, and which are overcharged with a large quantity of phlegm and light oil, is difficult. These distillations being slowly conducted with a gentle fire and water-bath, yield but a small quantity of that liquor, which, being the most volatile, rises first with the least heat, and which is the true or rectified spirit of wine. Several chemists, therefore, in order to obtain a larger quantity of the first spirit, propose to mix with the spirit of wine some intermediate substances, to absorb and retain its phlegm and oil, such as dried and calcined salts, very dry chalk, &c. Knuckel proposes to separate more effectually the oil, by adding to the spirit a large quantity of water, and by distilling this diluted spirit with a very gentle heat. But the trouble and inconvenience of depriving the spirit of wine of the water with which it was diluted in this process, may be avoided, by rectifying at once a large quantity of aqua vite. Nothing more is required to obtain at once a considerable quantity of pure spirit of wine, than to set aside the twelve or fifteen pints first drawn over from a large quantity, *e. g.* from three hundred pints of aqua vite, distilled with a very gentle fire in a large alembic. As the most spirituous, least aqueous, and least oily part of it always rises first, these twelve or fifteen pints are perfectly rectified spirit of wine, especially when the heat has been well conducted.

By thus keeping apart portions of the spirit obtained, at different times, we may have spirit of wine of the several degrees of strength and purity. The weaker spirit may, by another distillation, be again rectified; and the spirit of moderate strength may be preserved for many uses. The method is followed by M. Beaumé in the rectification of spirit of wine, and is certainly the most convenient and the best.

A perfectly rectified spirit of wine, or such as is entirely freed from water, is undoubtedly a thing of frequent and necessary use in the nice operations of chemistry.

It had used to be prepared, either by often distilling the spirit, and every time drawing over only half of it, and repeating this till the half remaining in the cucurbit appeared as strong as that drawn over; or else by raising it to a great height from the body of the vessel, and this in a very gentle heat, so that spirit alone could rise, the water not being capable of being driven so far by that degree of heat.

But the accurate Boerhaave always found upon trial, that there was still remaining some water in these spirits, whether prepared by the first or second process, or both. Boerhaave's *Chem.* part ii. p. 124.

The method he therefore invented is this: fill a still half full of the spirit prepared for alcohol in one or other of these ways, and add to it half a pound of pure decrepitated, and perfectly dried sea-salt; put this in hot, then place on the head, and carefully lute the junctures; leave this for twelve hours in a heat so small, as not to make the alcohol boil, then distil off the spirit; keep the first two ounces apart, because some aqueous vapour may have happened to lodge in the head or worm of the still, which this certainly washes off; after this receive two-thirds of the following alcohol into a pure dry glass vessel, and keep it perfectly stopped; then draw off the remainder, and keep that by itself: there will remain a moist salt in the still, which has attracted the aqueous matter of the alcohol, and held it so down, that it could not rise by the heat of boiling water,

which is all that must be used in this distillation; and the salt having been first decrepitated, never makes any change in the alcohol by adding any thing to it. By this means an alcohol is prepared perfectly pure, and fit for all the uses of chemistry.

For the tests and properties of pure alcohol, see *ALCOHOL*.

M. Reaumur discovered, that a mixture of spirit of wine and water acquired a specific gravity greater than that which would arithmetically result from the proportions employed of each of these liquors. Thus, fifty measures of spirit of wine, and fifty measures of water, mixed together, were found to make only ninety-eight measures; but in what progression the density is increased by mixing various proportions of the two liquors, had not been determined till M. Brillon made a set of experiments with that view; an account of which is given in the *Memoirs of the Academy of Sciences of Paris*, for the year 1769.

From his experiments he has constructed the following table, which shews this progression, and also enables us to discover the proportion of spirit of wine and water, in any given mixture of these (as brandies, rums, &c.), the specific gravity of which is found to correspond with any of the specific gravities in the table. Thus, for instance, if we find upon accurate trial, that the specific gravity of the rum, brandy, or other mixture, whose strength is required to be known, be to that of water as 942½ to 1000, we learn, by inspection of the table, that this spirituous mixture consists of equal parts of water and spirit of wine, of which spirit the strength is such, that its density is to that of the water as 837 to 1000. The first column shews the proportion of well rectified spirit of wine in the mixture; the second column shews the proportion of the water in the mixture; the third column shews the specific gravity of the mixture; the fourth column shews the difference between the specific gravity of the mixture and that of the preceding mixture; and the fifth column shews the proportion which the several augmentations of density, caused by penetration of the two liquors, have to each other, that is their progression.

Spirit of Wine.	Water.	Specific Gravity.	Differences.	Proportionable Augmentations of Density from Penetration.
Parts.	Parts.			
16	0	837	0	0
15	1	852½	15½	4½
14	2	867½	15	8½
13	3	881½	14	11½
12	4	894½	13½	13½
11	5	907½	12½	15½
10	6	919½	12½	17½
9	7	931½	12	19½
8	8	942½	10½	19½
7	9	951½	9½	18½
6	10	959½	8	17½
5	11	967½	7½	15½
4	12	973½	5½	11½
3	13	979	5½	7½
2	14	985	6	4½
1	15	991½	6½	1½
0	16	1000	8½	0

Spirit of wine is used in dyeing, as a non-colouring drug, and though it gives no colour itself, it serves to prepare the stuffs to receive other colours. Its consumption is also very

considerable in several other works and manufactures, particularly the making of varnish.

Proof-spirit cannot be used for burning in lamps, for dissolving resins, and for making varnish; and there is also a great number of tinctures, solutions, and mixtures, for which it cannot serve; but rectified spirit, or alcohol, besides its ready use for medicinal purposes, may, when the spirit is of a proper kind, be made into punch, and all other mixtures, with greater purity, and much greater certainty and exactness in point of strength. See next article and *ALCOHOL*.

SPIRITS, in the *Materia Medica*, "rectified spirit" of the London Pharmacopoeia; "alcohol," "spiritus vinosus rectificatus five purissimus," Edinb.; "spiritus vinosus rectificatus," Dub.; is alcohol nearly in the highest state of concentration in which it can be easily prepared in the large way for the purposes of trade. The London and Edinburgh colleges state its specific gravity to be to that of water as 835 to 1000, while the Dublin college states it at 840. The Edinburgh college names this spirit alcohol; but directions being given both by the London and Dublin colleges, for the preparation of a still stronger spirit, the name of alcohol, in their pharmacopoeias, is judiciously retained for the stronger spirit, while that of rectified spirit is applied to the present preparation.

The alcohol of the Lond. Ph. is prepared by taking of rectified spirit a gallon, and of subcarbonate of potash, three pounds: add a pound of the subcarbonate, previously heated to 300 degrees, to the spirit, and macerate for 24 hours, frequently shaking the mixture; then pour off the spirit, and add the remainder of the subcarbonate, heated to the same degree; and lastly, distil the alcohol from a water-bath, and preserve it in a well-closed vessel. The specific gravity of this alcohol is to that of distilled water as 315 to 1,000.

The alcohol of the Dub. Ph. is prepared by taking of rectified spirit of wine, a gallon; pearl-ashes, dried at a heat of 300°, and still hot, a pound; caustic kali, in powder, an ounce; muriate of lime, dried, half a pound. Mix the spirit and the kali; add the pearl-ashes, previously reduced to powder, and digest the mixture for three days in a closed vessel, frequently shaking it; then pour off the spirit; mix with it the muriate of lime; and lastly, distil with a moderate heat, until the residue begins to thicken. The specific gravity of this spirit is to that of distilled water as 315 to 1000.

Rectified spirit of the specific gravity of 835, contains about 15 per cent. of water; and to free it from this is the intention of the above processes. The Edinburgh college has no process for the preparation of pure alcohol, which may be easily dispensed with; but it has very improperly given this title to the rectified spirit of the other pharmacopoeias. The theory of the operation is sufficiently obvious. The affinity of the alkali and the muriate of lime for water is much greater than that of the spirit: it is, therefore, attracted by these substances, and prevented from rising with the spirit during the distillation, by which means the alcohol comes over in a very highly concentrated state. Of the two processes, that of the Dublin college is to be preferred; muriate of lime being a much more powerful agent for separating the water, which is the object in both, than subcarbonate of potash.

Dr. Black thus obtained alcohol of the sp. gr. of 800°, and Richter procured it so low as 0.792, in the temperature of 68° Fahr. at which degree of concentration it may be regarded almost as pure alcohol, or alcohol perfectly free from water. That of the pharmacopoeias is not free from water, though more than sufficiently concentrated for all the purposes of pharmacy.

The following Table, drawn up by Lowitz, with an additional column by Dr. Thomson, shews the specific gravity of different mixtures of pure alcohol, of a specific gravity .791, and distilled water, at the temperatures of 60° and 68° of Fahrenheit.

100 Parts by Weight.		Sp. Gravity.		100 Parts by Weight.		Sp. Gravity.	
Alcohol.	Water.	At 68°.	At 60°.	Alcohol.	Water.	At 68°.	At 60°.
100	—	791	796	49	51	917	920
99	1	794	798	48	52	919	922
98	2	797	801	47	53	921	924
97	3	800	804	46	54	923	926
96	4	803	807	45	55	925	928
95	5	805	809	44	56	927	930
94	6	808	812	43	57	930	933
93	7	811	815	42	58	932	935
92	8	813	817	41	59	934	937
91	9	816	820	40	60	936	939
90	10	818	822	39	61	938	941
89	11	821	825	38	62	940	943
88	12	823	827	37	63	942	945
87	13	826	830	36	64	944	947
86	14	828	832	35	65	946	949
85	15	831	835	34	66	948	951
84	16	834	838	33	67	950	953
83	17	836	840	32	68	952	955
82	18	839	843	31	69	954	957
81	19	842	846	30	70	956	958
80	20	844	848	29	71	957	960
79	21	847	851	28	72	959	962
78	22	849	853	27	73	961	963
77	23	851	855	26	74	963	965
76	24	853	857	25	75	965	967
75	25	856	860	24	76	966	968
74	26	859	863	23	77	968	970
73	27	861	865	22	78	970	972
72	28	863	867	21	79	971	973
71	29	866	870	20	80	973	974
70	30	868	871	19	81	974	975
69	31	870	874	18	82	976	
68	32	872	875	17	83	977	
67	33	875	879	16	84	978	
66	34	877	880	15	85	980	
65	35	880	883	14	86	981	
64	36	882	886	13	87	983	
63	37	885	889	12	88	985	
62	38	887	891	11	89	986	
61	39	889	893	10	90	987	
60	40	892	896	9	91	988	
59	41	894	898	8	92	989	
58	42	896	900	7	93	991	
57	43	899	903	6	94	992	
56	44	901	904	5	95	994	
55	45	903	906	4	96	995	
54	46	905	908	3	97	997	
53	47	907	910	2	98	998	
52	48	909	912	1	99	999	
51	49	912	915	—	100	1000	
50	50	914	917				

* Alcohol of the London and the Dublin Pharmacopias. † Ditto (Edinburgh); rectified spirit (London). ‡ Rectified spirit (Dublin). § Proof spirit (Lond. Dub.) | Ditto (Edinburgh).

In the extract from Mr. Gilpin's table (see *Specific Gravity*), the standard spirit was of the specific gravity of 0.825, or contained 89 pure alcohol, and 11 water, in 100 parts.

Pure rectified spirit has a fragrant odour, and a hot highly pungent taste. It is colourless; always fluid; cannot be congealed at any known degree of cold; evaporates speedily at the ordinary temperature of the atmosphere; boils at 163° Fahrenheit; and is extremely inflammable, burning with a blue lambent flame, without any sensible smoke. Like alcohol, it combines with water in every proportion; and, on account of its affinity for water, precipitates many of the neutral salts from their aqueous solutions. It is capable of dissolving many saline bodies, and is the proper solvent of the greater number of the proximate principles of vegetables. Its constituents are 85 of pure alcohol and 15 of water, in 100 parts, when its specific gravity is 835, at a temperature of 60° of Fahrenheit; but 83 only of pure alcohol, and 17 of water, when it is 840, as designated by the Dublin college.

Rectified spirit is a very powerful stimulant. In its undiluted state it is never exhibited as a remedy; and is merely employed for forming the diluted spirit, and as a pharmaceutical agent.

The "spiritus tenuior," or "weaker spirit," of the Lond. Ph.; the "diluted alcohol," the "spiritus vinosus tenuior five dilutus" of Edinb. Ph.; and "spiritus vinosus tenuior" of Dub. Ph., or "proof spirit," is merely rectified spirit diluted with a certain proportion of water. According to the London and Dublin colleges, its specific gravity should be to that of distilled water, as 930 to 1000; while the Edinburgh college orders it of the gravity of 935. The former may be formed by mixing four parts by measure of rectified spirit with three of water, and contains 44 parts of pure alcohol, and 55 of water, in 100 parts; the latter is obtained from equal parts of rectified spirit and water, and contains 42 of pure alcohol, and 58 of water, in 100 parts. Alcohol, diluted to the degree of proof-spirit, is still a very powerful diffusible stimulant, and too strong for internal use. Externally applied, it is recommended in burns; to restrain bleeding in passive hæmorrhages; and as a friction or fomentation to relieve muscular pains; and in a more diluted state it forms a good collyrium in the latter stage of ophthalmia. Proof-spirit diluted with water is employed as a remedy in the form of tinctures and spirits; and the ardent spirits in common use may be regarded as nearly of the same nature. These taken in moderation, increase the general excitement, communicate additional energy to the muscular fibres, strengthen the stomach, and exhilarate the mind. Hence they are often and advantageously used in cases of debility and low typhoid fevers, in which the use of wine is indicated; and in habits disposed to create acidity, they are even preferable to wine; some of them, particularly brandy, proving gratefully stomachic, when wine is nauseated and rejected. As an article, however, of daily or dietetical use, particularly if taken in immoderate doses, or long continued, ardent spirits, besides being the source of much moral evil, and debasing the human character nearly to a level with that of brutes, are apt to occasion disease, and are commonly the origin of dyspepsia, hypochondriasis, and hepatic and visceral obstructions. The hurtful effects of ardent spirits, however, are obviated in a considerable degree by diluting them with water, and adding lemon-juice and sugar to the mixture, so as to form what is generally known by the name of punch. Although all the varieties of ardent spirits may be regarded as diluted alcohol, yet each has a peculiar operation: thus,

brandy is simply cordial and stomachic; rum, heating and sudorific; gin and whisky, diuretic; and arrack, styptic, heating and narcotic, and ill adapted to European constitutions.

Vinous spirits, therefore, in small quantity, and properly diluted, may be applied to useful purposes in the relieving of some disorders; whilst in larger ones, or imprudently continued, they act as a poison of a particular kind. The moderate use of them is most serviceable to those who are exposed to heat and moisture, to corrupted air, or to other causes of colliquative and putrid diseases; and they are the most pernicious in opposite circumstances, and to those who are afflicted with hysterical and hypochondriacal complaints: for whatever temporary relief these spirituous cordials may afford in the lownesses to which hysterical and hypochondriacal persons are subject, there are none, as Dr. Pemberton observes, who feel so soon the ill effects arising from the habitual use of them. Lewis's Mat. Med.

The power of brandy, or any thing of this kind, in killing worms, is evident from this, that the children of the people in the northern islands of Scotland, who are accustomed from their infancy to drink that coarse sort of brandy which they call aqua vita, never are troubled with worms. It is a dangerous practice to use brandy in this general manner, but on some occasions it may be very serviceable. *Philos. Transf.* N° 233.

SPIRITS, Laws relating to Foreign and British. By a variety of statutes, which it would be too tedious here to enumerate, duties both permanent and temporary, of the customs and the excise, have been imposed on brandy, rum, arquebushade, geneva, arrack, and spirits, the amount of which is very considerable in proportion to the original price. By 43 Geo. III. c. 69. (sched. A), and 43 Geo. III. c. 81. several duties are imposed upon spirits imported; but by 49 Geo. III. c. 98. several duties of customs are imposed: the said duties are payable by the importer, before landing. If any person shall land any French brandy, before the duty be paid or secured, or without licence from the proper officer, and conceal the same when landed, he and his aider shall not only forfeit the same, but also double value; and if any officer of the customs or excise shall connive at it, he shall forfeit 500*l.*, and be incapable of holding any office in the revenue. (1 Ann. stat. 2. c. 14.) The officers of excise may go on board any ship and search, as officers of the customs may do, for any exciseable liquors, and seize such as shall be forfeited, and such as shall be unshipped before entry and payment of the duties, together with the casks and other package. (11 Geo. I. c. 30.) Any officer of the excise may search for concealed foreign spirits, and seize, &c.; and the penalty of obstruction is a forfeiture of 100*l.* By a general clause in 8 Geo. I. c. 18. all brandy, arrack, rum, spirits, and strong waters, and all foreign exciseable liquors, forfeited, together with the casks and package, may be seized by any officer of the customs or excise, or persons deputed from the lord treasurer, or undertreasurer, or by special commission under the great or privy seal, and no other person; and the penalty of obstruction is 40*l.* If any foreign brandy, arrack, rum, or strong waters, or spirits of any kind, shall be imported in any vessel of 100 tons burden, or under, (except for the use of seamen, not exceeding two gallons each,) such vessel, with its tackle, and also the spirits, shall be forfeited (5 Geo. III. c. 43.): except rum or other spirits of the growth and manufacture of the British sugar plantations, which may be imported in any vessel of not less burden than 70 tons. (6 Geo. III. c. 46.) If any vessel of 50 tons, or under, partly or fully laden with brandy, be at anchor or within two leagues of the

shore, and not proceeding on her voyage, if wind and weather permit, such vessel may be compelled by the commander of any man of war, or armed sloop appointed to guard the coast, or the commander of any vessel in the service of the customs, to come into port; and the case is the same with ships hovering near the coasts. (6 Geo. I. c. 21.) If any vessel come from foreign parts, and have on board any foreign brandy or spirits, in casks under six gallons, (except for the use of seamen, not exceeding two gallons each,) shall be found at anchor, &c. as in the former case, all such spirits, with the casks and package, or value, shall be forfeited, and the same may be seized, or value sued for by the officers; and if the vessel do not exceed 50 tons in burden, the said vessel, with her tackle and furniture, shall be forfeited: and if any person, having charge of the vessel, shall suffer any brandy to be put into lighters or boats, in order to be landed, he shall, besides other penalties, suffer six months' imprisonment. No brandy shall be imported in any vessel not containing 60 gallons at the least, on pain of forfeiting the same, or value. (4 W. c. 5.) And no geneva or rum shall be imported in any vessel or cask, not containing 60 gallons at least, (except for the use of seamen, not exceeding two gallons each,) on pain of forfeiture. (5 Geo. III. c. 43.) If any officer shall find any increase of rum or spirits, (except such as have been imported and lodged in a warehouse, according to law,) above the quantity found on the last survey, or any decrease, (beyond the quantity legally delivered or allowed for leakage,) the proprietor or importer shall forfeit 500*l.*; and opening the warehouse, except in the presence of the warehouse-keeper or excise officer, incurs a forfeiture of 500*l.* If any rum or spirits remain in the warehouse above twelve calendar months (6 Geo. III. c. 47.), without paying the duty, the commissioners of excise may sell them by auction, and pay the duty and charges, transferring the overplus to the proprietor or importer. A permit shall be obtained for removal of the quantity sold; nor shall any liquor, exceeding one gallon, be carried away without such permit, on pain of forfeiting the same, with the casks and vessels. If the liquor be not removed, and the permit not returned, the person that took it out shall forfeit treble value. No person shall receive a permit, without direction in writing of the person (or his servant) from whose stock the goods are to be removed, on pain of 50*l.*; and in default of payment, three months' imprisonment. No foreign spirits, although under one gallon, shall be received into the custody of any retailer, without a permit, signifying that the duties were paid, or that they had been condemned, on pain of forfeiting the same. (8 Geo. I. c. 18.) No seller or dealer shall be allowed to take out more than one permit in one day; provided that several permits may be taken out, and casks containing foreign spirituous liquors sent to the same persons the same day, so that each cask may be sent under different permits, and by different conveyances; and provided dealers shall not be prevented from sending with one permit by one and the same conveyance any number of casks, containing 60 gallons each, or upwards, of the same kind. Foreign spirits, not being casks of 60 gallons, or upwards, shall not be removed, unless at the following times; that is, from September 29th to March 25th, yearly, between the hours of seven in the morning and five in the evening; and from March 25th to September 29th, between the hours of five and seven, (except the same is carrying by a known common stage-coach, waggon, or other stage carriage, usually travelling out of these hours,) on pain of forfeiture, with or without a permit. (23 Geo. III. c. 70.) No foreign spirits more than 60 gallons shall be brought to London by

one permit, or one conveyance, at the same time, from any part of England by land or water, (except by Gravesend, in the ordinary course of commerce,) on pain of being seized and forfeited. (26 Geo. III. c. 73.) If any person shall counterfeit a permit, or give or receive any false permit, or alter any granted by the proper officer, he shall forfeit 500*l*. 23 Geo. III. c. 70.

For the conditions, regulations, and restrictions, under which rum imported from the West Indies may be secured in warehouses, without payment of duty, see 43 Geo. III. c. 132. 45 Geo. III. c. 87. 46 Geo. III. c. 137. and 48 Geo. III. c. 126; and for those under which brandy, geneva, and other spirits, may be secured in warehouses, without payment of duty, see 43 Geo. III. c. 132. 45 Geo. III. c. 87. 46 Geo. III. c. 137. and 48 Geo. III. c. 126. For other laws and regulations, see CUSTOMS, DISTILLER, EXCISE, SMUGGLING, and WINE.

Spirit of Ammonia, in the *Materia Medica*, is prepared, according to the directions of the Lond. Ph., by mixing two pints of rectified spirit with a pint of solution of ammonia. The "ammoniated alcohol," formerly *spirit of ammonia*, of the Ed. Ph., consists of 32 oz. of alcohol (835), 12 oz. of lime recently burnt, and 8 oz. of muriate of ammonia; and is prepared in the same manner as water of ammonia. (See AMMONIA.) The *spirit of ammonia* of the Dub. Ph. is prepared by mixing three pints of proof-spirit, 4 oz. of muriate of ammonia, and 6 oz. of potashes; and distilling, with a moderate heat, two pints. This spirit, properly prepared, has the pungent odour and acrid taste of ammonia, with which it coincides in its medicinal properties. (See AMMONIACAL Preparations.) It is chiefly used for pharmaceutical purposes. The official preparations are "spiritus ammonia compositus," "spiritus ammoniac fortidus," "tinctura castorei composita," "tinctura guaiaci composita," and "tinctura opii composita."

Spirit of Ammonia, Aromatic, is prepared, according to the Lond. Ph., by mixing two pints of spirit of ammonia with oil of lemon and oil of cloves, of each two fluid-drachms. The "aromatic ammoniated alcohol," formerly *aromatic spirit of ammonia*, of the Edinb. Ph., is composed of 8 oz. of ammoniated alcohol, 1½ drachm of volatile oil of rosemary, and a drachm of volatile oil of lemons, which are mixed so as to dissolve the oils. The *aromatic spirit of ammonia* of the Dub. Ph. is formed by digesting two pints of spirit of ammonia, two drachms of essential oil of lemons, and half an ounce of bruised nutmegs, in a covered vessel for three days, frequently shaking the vessel; and then distilling a pound and a half. This spirit is an useful stimulant in languors, and flatulent colic; and the oils render it more grateful to the stomach than the simple spirit of ammonia. The dose is from fʒss to fʒj, in any convenient vehicle. The official preparations are "tinctura guaiaci ammoniata," and "tinctura valerianae ammoniata."

Spirit of Ammonia, Fetid, is prepared, according to the Lond. and Dub. Ph., by macerating two pints of spirit of ammonia, and 2 oz. of assafetida (1½ oz. Dub.), for 12 hours (for three days, in a covered vessel, with frequent agitation, Dub.); and then by a gentle fire distilling a pint and a half into a cold receiver. The "fetid ammoniated alcohol," formerly *fetid spirit of ammonia*, of the Edinb. Ph., is prepared by digesting 8 oz. of ammoniated alcohol, and ½ oz. of assafetida, in a close vessel for 12 hours, and then distilling 8 oz. by the heat of boiling water. The medicinal properties of this spirit, and the dose, are the same with those of the preceding. It acquires colour from age.

Spirit of Ammonia, Succinated, of the Lond. Ph., is prepared by macerating three drachms of mastic in nine fluid-drachms of alcohol, so that it may be dissolved, and pouring off the clear tincture; then adding fourteen minims of oil of lavender, four minims of oil of amber, and ten fluid-ounces of solution of ammonia, and mixing them by agitation. This spirit is employed as a stimulant and antispasmodic, in the same cases as the oil of amber, and has been used with success in India against the bite of the rattlesnake. The dose is from ℥x to fʒss, in any convenient vehicle. See AMBER.

Spirit of Anise-seed of the Lond. Ph. is formed by macerating for 24 hours half a pound of anise-seeds bruised, a gallon of proof-spirit, and a sufficient quantity of water to prevent empyreuma, and distilling by a gentle fire. The *compound spirit of anise-seed* of the Dub. Ph. is obtained by distilling one gallon from anise-seeds and angelica seeds bruised, of each half a pound, a gallon of proof-spirit, and water sufficient to prevent empyreuma. In flatulent colic, and similar affections, these are pleasant carminatives. The dose is from fʒss to fʒiv, in water.

Spirit of Horse-radish, Compound, "spiritus armoraciz compositus," of the Lond. Ph., is prepared by macerating fresh horse-radish sliced and orange-peel dried, of each a pound, half an ounce of nutmegs bruised, a gallon of proof-spirit, and water sufficient to prevent empyreuma, for 24 hours, and distilling a gallon by a gentle fire. (See COCHLEARIA.) The "compositus spiritus raphani," of the Dub. Ph., is formed by distilling two gallons from horse-radish dried and peel of Seville oranges, of each two pounds, four pounds of fresh garden scurvy-grass, one ounce of nutmegs bruised, two gallons of proof-spirit, and water sufficient to prevent empyreuma. These spirits, which were formerly used as antiscorbutics, are now held in little estimation in that intention. They are chiefly used in dropsies, attended with much debility. The dose is from fʒj to fʒiv, combined with infusion of fox-glove or juniper-berries.

Spirit of Camphor of the Lond. Ph. is prepared by mixing four ounces of camphor with two pints of rectified spirit, that the camphor may be dissolved. The "tincture of camphor," commonly called the "camphorated vinous spirit," is obtained by mixing one ounce of camphor with one pound of alcohol (sp. gr. 835), so that the camphor may be dissolved. It may be also made with double or triple the quantity of camphor. This spirit is too strong to be given internally; and if water be mixed with it, the camphor is separated. It is an useful stimulant and discutient application to chilblains, and in chronic rheumatism, paralytic numbness, and gangrene. See CAMPHOR.

Spirit of Carraway of the Lond. and Dub. Ph. is obtained by macerating a pound and a half (half a pound, Dub.) of carraway seeds bruised in a gallon of proof-spirit, and water sufficient to prevent empyreuma, for 24 hours, and distilling a gallon by a gentle fire. The *spirit of carraway* of the Edinb. Ph. is prepared by macerating half a pound of carraway seeds bruised in nine pounds of proof-spirit, for two days in a close vessel, adding water enough to prevent empyreuma, and distilling nine pounds. This spirit is an useful carminative, and an adjunct to griping purgatives. See CARUM.

Spirit of Cinnamon of the Lond. and Dub. Ph. is prepared by macerating one pound of cinnamon bark bruised in a gallon of proof-spirit, and water sufficient to prevent empyreuma, for 24 hours, and distilling a gallon by a gentle fire. The *spirit of cinnamon*, "spiritus corticis lauri cinamomi," of the Edinb. Ph., is prepared with a pound of cinnamon bark, in the same manner as the spirit of carraway.

This spirit is an agreeable cordial in diseases attended with much languor and debility. The dose is from f3j to f3iv, in any suitable vehicle. The officinal preparation is "infusum digitalis." See CINNAMON.

SPIRIT, *Coal*. See COAL.

SPIRIT of *Sulphuric Ether* of the Lond. Ph. is obtained by mixing half a pint of sulphuric ether (see ETHER) with a pint of rectified spirit. The "sulphuric ether with alcohol," of the Edinb. Ph., is prepared by mixing one part of sulphuric ether with two parts of alcohol. The specific gravity of this mixture is .816. It may be used for the same purposes as the ether, but it is much less active. The dose is from f3j to f3iij. An useful gargle for slight inflammation of the fauces is prepared by adding f3j of this spirit to f3vi of boiling water, sweetened with f3iv of syrup of marsh-mallows. The sulphuric ether, of which this is an officinal preparation, is stimulant, narcotic, and antispasmodic. In its operation it resembles alcohol, but is more diffusible, and its effects are less permanent. It is beneficially employed as a cordial in typhoid and low fevers, particularly when nausea, subultus tendinum, and other spasmodic symptoms are present. As an antispasmodic, it relieves the paroxysm of spasmodic asthma, whether it be taken into the stomach, or its vapour only be inhaled into the lungs; in which latter form it is also useful in simple dyspnoea and in catarrh. It is employed with advantage in hysteria, tetanus, cramp of the stomach, hiccough, and in cholera morbus to check the vomiting; and also allays the violence of sea-sickness. The usual dose of sulphuric ether is from f3fs to f3ij; but it has been given in much larger doses with the most beneficial effects; and in all cases, the dose must be repeated at short intervals, to produce the full effect of the remedy. As an external application, ether acts either as a stimulant or a refrigerant, according to the mode in which it is applied. The first takes place when it is prevented from evaporating, by being confined over the spot to which it is applied; in which case it often proves useful in relieving head-ache, and other muscular pains; and from its refrigerant effect produced by its rapid evaporation, it is applied to burns, and to assist in the reduction of strangulated hernia. It has produced, says Thomson (Lond. Disp.), almost immediate relief in ear-ache, when dropped into the external meatus.

SPIRIT of *Ether, Aromatic*, of the Lond. Ph., is obtained by macerating three drachms of cinnamon bark bruised, a drachm and a half of cardamom seeds powdered, long pepper powdered and ginger-root sliced, of each a drachm, in a pint of spirit of sulphuric ether, for 14 days, in a stoppered glass-bottle, and straining. The "aromatic sulphuric ether with alcohol," of the Edinb. Ph., is made with the same aromatics, and in the same manner as the compound tincture of cinnamon, except that sulphuric ether with alcohol is employed instead of proof-spirit. The medicinal properties of these preparations are the same with those of the former; the aromatics rendering them in a slight degree more grateful.

SPIRIT, *Ethereal, of Frobenius, Spiritus Etherius Frobenii*, a name given by Frobenius, and others, to a liquor famous for its extreme volatility, and many other qualities; for which see *Sulphuric ETHER*.

The use of this liquor in medicine is now well known: as a very thin and volatile inflammable matter, it acts powerfully on the nervous system. Frederic Hoffman was one of the first who employed it as a sedative and antispasmodic. See LIQUOR *Mineralis Anodynus*, and SPIRIT of *Ether*, *infra*.

It is now often prescribed singly, in the dose of seven or

eight drops upon a bit of sugar, which is to be eat, or to be dissolved in some proper liquor, and drank. It is given in flatulent colics, obstinate hiccoughs, convulsive hysterical affections, and other disorders of this kind. This ether is said to take spots of grease from silk, without affecting their colours.

We have several curious observations on this ether of Frobenius by Mr. Grosse, who has described three different methods of making it in the Memoirs of the Academy of Sciences, for the year 1734.

SPIRIT of *Ether, Compound*, of the Lond. Ph., is prepared by mixing a pint of spirit of sulphuric ether with two fluid-drachms of ethereal oil. (See *Sulphuric ETHER*.) This is intended as a substitute for the anodyne liquor of Hoffman (see the preceding article); for, besides being stimulant and antispasmodic, it is supposed to possess anodyne properties. It is an useful addition to tincture of opium, when given for the purpose of procuring sleep; and it often prevents the opium from exciting the nausea which it is apt to produce in some habits. The dose is from f3fs to f3ij, in any appropriate vehicle.

SPIRIT of *Juniper, Compound*, of the Lond., Dub., and Edinb. Ph., is prepared by macerating one pound of juniper-berries bruised, carraway seeds and fennel seeds bruised, of each an ounce and a half, in a gallon (nine pounds, Edinb.) of proof-spirit, for 24 hours (two days, Edinb. and Dub.); and then distilling a gallon (nine pounds, Edinb.) by a gentle heat. This spirit is a grateful and useful addition to infusions of fox-glove, and other diuretics, in dropsy. See JUNIPERUS.

SPIRIT of *Lavender*. See LAVANDULA.

SPIRIT of *Libanus, Smoking*. See LIQUOR.

SPIRIT of *Malt*. See MALT-Distillery.

SPIRIT of *Mindererus*. See ACETITE of *Ammonia*, LIQUOR, and VINEGAR.

SPIRIT, *Molossis*. See MOTOSES-Spirit.

SPIRIT of *Nitre*. See NITRIC Acid, and Nitrat POTASSÆ.

SPIRIT of *Nitric Ether* of the Lond. Ph. is obtained by taking two pints of rectified spirit, and three ounces (by weight) of nitric acid. Add the acid gradually to the spirit, and mix them, taking care that the temperature, during the mixture, does not exceed 120°; then distil, by a gentle heat, 26 fluid-ounces. *Spirit of nitrous ether* of the Edinb. Ph. is prepared by pouring three pounds of alcohol into a large phial placed in a vessel full of cold water, and adding one pound of nitrous acid gradually, with frequent agitation. Slightly cork the phial, and place it in a cool place for seven days; then distil the liquor, by the heat of boiling water, into a receiver kept cool with snow or water, as long as any spirit comes over. The *nitrous ethereal spirit* of the Dub. Ph. is prepared in the following manner: Add to the matter which remains after the distillation of nitrous ether, the rectified spirit of wine, employed in that operation for condensing the elastic vapour, and distil to dryness, with the greater heat of a water-bath. Mix the distilled liquor with the alkaline liquor which remains after the separation of the nitrous ether, and also add as much dry sub-carbonate of kali as shall be sufficient to saturate the predominant acid; which is to be determined by the test of litmus. Lastly, distil by the medium heat of a water-bath, as long as any fluid comes over. The specific gravity of this liquor is to that of distilled water, as 850 to 1000. The spirit of nitric ether, as procured by the London or Edinburgh process, has an extremely fragrant odour, and a pungent acidulous taste. It is very volatile and inflammable, soluble in water and alcohol, and strikes a deep

olive with solution of green sulphate of iron. See *Nitrous Ether*.

Spirit of nitric ether is refrigerant, diuretic, and antispasmodic. It has been long known and used, under the title of "sweet spirit of nitre," as a grateful refrigerant, and for quenching thirst in febrile affections; for which purpose the dose is from ℥xx to ℥xl, given in a cupful of water, or any other appropriate vehicle. In larger doses it acts as a gentle stimulant to the stomach, relieving nausea and flatulence; and also determines to the kidneys, increasing the flow of urine; on which account it is advantageously prescribed as an auxiliary to other diuretics in dropical complaints. The dulcified spirit of nitre is added by drops to potions and juleps, till it has given them an agreeable acidity.

It is also much used by our distillers to give a vinosity to those spirits, whose natural flavour of that kind they have destroyed by the improper use of alkaline salts in the rectifications. Nothing can be more proper for this purpose than this spirit, as it really gives the brandy-flavour, and is not at all prejudicial to health, but very well falls in with the nature of the spirit, and promotes its medicinal properties as a diuretic, deobstruent, and lithontriptic.

It has been suggested, that the method of making it for this purpose is improveable, by using in the preparation a spirit of wine impregnated with some fine flavoured ingredient, which has not much oil, for acids do not readily mix where there is much oil.

In the preparation of this dulcified spirit of nitre, the longer it stands in digestion with the spirit of wine, the milder it grows; and by the same means also, the violently corrosive oil of vitriol may be so blunted, as to be rendered scarcely perceptible to the taste. In fine, it has been said that a spiritus nitri dulcis may be made, by a slow digestion, greatly superior to that commonly used, and of so fixed a nature, that it will not be subject to have its flavour fly off from the spirit with which it is mixed, any sooner than the native vinosity of brandy will of itself fly off from that spirit, as it always will in time. A proper care in the preparation of this acid might free the distillers from that troublesome

necessity they are under of adding their spirit of nitre, just before they send their goods away, for fear the flavour should be lost before the spirit is wholly used, and so the sophistication be found out. There is no fixing any certain proportion in which the acid is to be mixed with the spirit, but in general it is best not to over-do it; for though it will give an agreeable vinosity to any tolerable clean spirit, the person will be much deceived who attempts to draw the bad flavour of a foul one by it. Shaw's Essay on Distillery.

Mr. Woulfe describes an apparatus by which *nitrous ether* (in the article under *ETHER*) may be expeditiously obtained by distillation, with the heat only occasioned by mixing together the nitrous acid and the spirit of wine. This distillation is performed in a matrass with a high neck, to which is fitted a head with a spout, communicating with the receiver by means of a long tube. The vapours that are not condensed in this receiver, or in a bottle joined to a spout in its bottom, are conveyed from the receiver through a bent tube into spirit of wine contained in a bottle. If any vapours pass uncondensed through this spirit of wine, they are conveyed through another bent tube into more spirit of wine contained in another bottle. The liquor collected in the bottle annexed to the receiver, being slowly rectified with slaked lime, furnishes very fine ether. The spirit of wine in which the vapours were condensed, contains so much ether, that this fluid may be separated from the spirit by adding water. This spirit of wine is by the operation changed into good dulcified spirit of nitre. Phil. Trans. vol. lvi. art. 59.

SPIRIT of Sal Ammoniac. See *AMMONIACAL Preparations*.

SPIRIT of Salt. See *MURIATIC Acid*.

SPIRIT of Sulphur, or of Vitriol. See *SULPHURIC Acid*.

SPIRIT of Turpentine. See *TURPENTINE*.

SPIRIT of Venus. See *ACETIC Acid*.

SPIRIT of Vinegar. See *ACETOUS Acid*, and *VINEGAR*.

SPIRIT of Vitriol. See *SULPHURIC Acid*, and *VITRIOL*.

SPIRIT of Wine. See *ALCOHOL* and *WINE*.

Spotting

SPOTTING, FINGER, known also by the name of *Brocading*, in the *Manufacture of fanciful ornamented Cloths*, is a very beautiful, though rather expensive, mode of interweaving flowers, either of the same or different colours, with various kinds of grounds. Of its primary origin we are totally unacquainted, as we find it practised alike, and with little variation of apparent effect, in the silks of Europe and the muslins of India. It is probable that the whole range of fanciful cloths, with which we are acquainted, are originally Asiatic; and that the knowledge of them has gradually reached Europe, at various times, and through various channels. In spots wrought with the shuttle, the flowers being at intervals, and the woof passed across the whole fabric, what passes between the flowers, and is not interwoven with the fabric, must be cut away, when the cloth is taken from the loom, and before it undergoes the succeeding processes of bleaching and dressing. Some specimens of brocaded muslins have been occasionally brought from India, which are entirely effected by a continued and patient exercise of manual labour truly astonishing. The low price of labour paid to the natives of that country may produce these figured muslins, at prices accessible to the opulent natives, and to the more wealthy classes of the European settlers. In this country, even at the most reduced prices, capable of affording to the operative the

most penurious and scanty subsistence, they could not be afforded under four or five guineas *per* yard; a sum immensely beyond what could be expected for a commodity so flimsy and perishable as a muslin dress.

In finger-flowers, or brocaded muslins, the draught through the heddles is generally successive from the back to the front, as in most kinds of fanciful weaving. The treddles are moved by the feet, as in the common processes, for forming the plain ground or fabric of the work. For the flowers or raised part, those leaves which require to be raised are most commonly pulled by cords above the weaver's head, as in the diaper and patent draw-loom; and, like them, secured by a knot upon the cord, being fixed in a notch in the board. The weaver then proceeds to pass the substance, which is to form the flowers, through the warp; each end being separated from, and independent of, all the others. In this he is generally assisted by a boy, who sits at the loom along with him, and who manages one side of the web, while the weaver is employed on the other. From this tedious and laborious operation being done entirely by the fore-finger, the appellation *finger-flower* is derived. Our limits will not allow of a very lengthened detail, nor would it be of any essential service; for, from the causes already assigned, there is no probability of its ever becoming an article of extensive manufacture in this country.

Staffordshire

STAFFORDSHIRE is an inland county, situated nearly in the centre of England, between 52 and 54 degrees N. latitude, and between one and three degrees W. longitude from London. It is in shape an irregular parallelogram; and is bounded on the N. by Cheshire and Derbyshire, on the E. by Leicestershire, on the S. by the counties of Warwick and Worcester, and on the W. by Shropshire. Its greatest length from N.N.E. to S.S.W. is about 60 miles, and its greatest breadth from E. to W. 38 miles. The superficial contents are about 780,800 acres, of which 100,000 are pasture, 500,000 arable, and the remaining 180,800, woods, waters, wastes, &c.

Ancient State: Historical Events.—This county appertained to the Cornavii of the Britons, to the division of Flavia Cæsariensis of the Romans, and was a part of the kingdom of Mercia during the Saxon heptarchy. Bede calls the inhabitants Angli-Mediterranei, the midland English. The two Roman military ways, Watling-street and Icknield-street, pass through this county. The former enters it out of Warwickshire, near Tamworth, and running westward passes into Shropshire. Icknield-street also enters from Warwickshire at the village of Hansworth, near Birmingham, crosses Watling-street, and enters Derbyshire at Monk's bridge. The Roman stations in this county that are known, are Pennoerucium, near Stretton; and Etocetum, at Wall near Lichfield. But Salmon gives to Staffordshire four Roman stations, which, he says, are Mediolanum, at Knightley; Uriconium, at Wrottesley; Uxacona, at Wall-Lichfield; and Etocetum, at Barbeacon. The first of these stations Camden positively fixes in Montgomeryshire; and bishop Horsley places it on a slip of land inclosed by the Tern and another river. Salmon assigns Pennoerucium to Oldbury, in Warwickshire, and refers to Antoninus's second Itinerary for his authority; but Plot, Gale, Horsley, and Stukeley, coincide in opinion that Penkridge is the site of that station. The ancient inhabitants of Staffordshire, in the opinion of Dr. Plot, were the Iceni; but in this he stands unsupported: Shaw says that tribe was undoubtedly of Derbyshire. Camden and Gough will not allow that they extended beyond Huntingdonshire, westward; while Salmon confines them to Norfolk and Suffolk. Shaw supposes that the Ordovices were the original inhabitants of this district, and it is generally agreed that they possessed it many centuries before the Christian era. These were an intrepid warlike people, whose territories comprised a great portion of Wales and several counties of England. But they were disturbed in their possessions by the Cornabii, who, breaking through the limits of their original settlements on the banks of the Dee, conquered a large tract of country to the west and north-west, and established a monarchy, of which Condate was the capital. The Brigantes, in their turn subdued

a portion of the territories of this tribe a short time previous to the arrival of the Romans. On this event the metropolis was transferred from Condate to Uriconium, now Wroxeter, where it continued a considerable time, till the Romans extended their conquest into the interior of the country. During the sanguinary contests which ensued, little is recorded respecting this district and its inhabitants, but that they heroically resisted the invaders, and though at length compelled to submit, their courage and ardour for freedom excited the admiration of their conquerors. The Cornabii, after the subjection of their country, appear to have been the friends and allies of the Romans. It is remarkable that after the decline of the Roman power, the appellation Cornabii never occurs in the annals of English history. When the Britons experienced a second subjugation by the Saxons, and the heptarchy was established, Staffordshire formed a part of the kingdom of Mercia, which extended over all the midland counties, and was founded by Crida in the year 585. During the repeated invasions of the Danes, this county sustained a considerable part of the calamities consequent on their cruelty and rapacity. Several sanguinary battles took place within the kingdom of Mercia; in Staffordshire particularly, two victories were obtained over the Danes in the reign of Edward the Elder. On the partition of England between Edmund Ironside and Canute, this county, as part of Mercia, was awarded to the latter. After the Norman conquest, William divided the estates of the Mercian earls among four of his principal followers, Hugh de Montgomery, earl of Arundel; Robert de Stafford, Henry de Ferriars, and William Fitz-Ansculph; the last of whom held twenty-five manors in this county. The other principal landholders besides the king, were the bishop of Chester, the abbots of Westminster and Burton, the church of Rheims, and the canons of Stafford and Wolverhampton. During the contention between the royal houses of York and Lancaster, a decisive battle was fought at Bloreheath, in this county, between the Yorkists under the earl of Salisbury, and the Lancastrians under lord Audley, when the latter, with double the force and superior position, was completely defeated, himself slain, and 2400 Cheshire gentlemen, whose attachment to king Henry led them into the van, also fell in the action.

In the civil war of the seventeenth century, Staffordshire was considerably engaged: Stafford surrendered to the parliament's forces, and Lichfield was several times taken and retaken by the contending parties. In this county Charles II. lay concealed after the fatal battle of Worcester, till he had an opportunity of escaping. The circumstances attending his concealment, the difficulties he sustained, and the unshaken loyalty of his friends, are amply detailed by Mr. Shaw in his *General History of Staffordshire*.

Ecclesiastical History.—Staffordshire did not receive the light of the gospel till the reign of Penda, king of Mercia, whose son, Peadda, was converted to Christianity by the venerable Bede. This was soon declared the established religion of Mercia, and the cathedral of Lichfield was founded, where the episcopal see of Mercia was fixed in 669; but it was soon afterwards divided into five several dioceses, and Lichfield, Worcester, Hereford, Leicester, and Sidnacester, chosen for the respective sees. In the year 786, at the request of king Offa, pope Adrian advanced Lichfield to the dignity of an archbishopric; but this distinction was continued only till the death of Offa, when pope Leo reduced it to its former rank. About the year 1067 the episcopal seat was removed to Chester, and thence soon afterwards to Coventry, where it continued till the end of the thirteenth century, when Walter de Langton was appointed bishop of Lichfield and Coventry. From this period nothing remarkable occurred in Staffordshire, connected with church history, previous to the reformation, when Lichfield cathedral was despoiled of the rich shrine of St. Chad, and the see of Coventry separated from it. The two bishoprics remained distinct till the restoration, when they were again united in the person of Dr. John Hacket. Since that time the diocese has undergone no particular alteration. Staffordshire, which is comprised in this see, contains 181 parishes.

Civil Division.—Staffordshire is divided into five hundreds; Totmanslow, Pyrehill, Cuddlestone, Offlow, and Seifdon: and contains one city, Lichfield, and twenty-three other market-towns, viz. Stafford, Wolverhampton, Walsall, Burton-on-Trent, Uttoxeter, Newcastle, Leek, Stone, Cheadle, Eccleshall, Rudgeley, Tamworth, Tutbury, Abbot's-Bromley, Breewood, Penkridge, Cannock, Wednesbury, Burslem, Handley-Green, Lane-End, and Longnor. Ten members are returned to the imperial parliament from this county, viz. two for the shire, and two each for Lichfield, Stafford, Newcastle, and Tamworth. According to the population survey of the year 1811, this county contained 57,040 houses, occupied by 295,153 persons; of whom 34,011 families were chiefly employed in trade and manufactures, and 18,361 in agriculture.

General Aspect, Soil, and Climate.—The appearance of the county varies in different districts. The middle and south portions are generally level: among the few exceptions are the hills of Dudley and Sedgeley, the quartose and ragstone hills of Rowley, and those of Clent and Barbeacon. The grounds of Byshbury and Essington, and some situations near Tettenhall and Enville, as well as on Cannock-heath, are also considerably elevated. The latter portion of the county was in ancient times covered with oak, but most of these have been destroyed: indeed scarcely a tree now remains to enliven the prospect, through an extent of 2500 acres. The northern portion of the county is of an opposite character to that on the south. Here the surface is mostly bleak and hilly: only a few of the eminences, however, rise to any remarkable elevation. The summit of Bunter, near Ilam, was found by Mr. Pitt, in the course of his "Agricultural Survey," to be 1200 feet above the level of the Thames. The Weever hills, and some other points, he reports as ascending even 1500 feet. The general elevation of this district above the southern is estimated at from one to two hundred yards. That portion of it called the moorlands, is the commencement of that range of mountains which extend through the centre of England, till they enter Scotland, acquiring different appellations in their progress, and increasing in altitude as they approach the north. The soil is extremely varied. The arable soils may be divided generally into the argillaceous, or stiff and strong clayey;

the arenaceous, or loole, light, and sandy; the calcareous, or lime earth; and a mixed or compound soil, or loam composed of the foregoing, with the addition of stones and other matters. The climate of this county inclines to wet: the annual rains are calculated at upwards of 36 inches, and thus exceed by nearly 16 inches the average computation of rain in London. A great quantity of snow falls in the moorlands, which doubtless is a principal cause of the piercing cold which prevails in that district.

Rivers.—Staffordshire abounds with rivers, but none of them are navigable, at least within the county. The principal are the Trent, the Dove, the Tame, and the Blythe. The Trent, which may be considered as the third river of England, waters, in its course to the sea, some of the most fertile and best cultivated districts of the kingdom. During its passage through Staffordshire, its banks are covered with luxuriant meadows. In the vicinity of Trentham, the seat of the noble family of Gower, the efforts of art have greatly added to the natural beauty of the river, by swelling it into an expansive lake. Passing the town of Stone, it flows through a valley diversified with a variety of elegant parks; of which that of Wolfsey, bordering on the chase of Cannock, is one of the most remarkable for the romantic beauty of its scenery. Pursuing its course, the Trent becomes the boundary between the counties of Stafford and Derby, till its junction with the river Dove; then, crossing Derbyshire, it runs through the counties of Nottingham and Lincoln, and at length pours its waters into the Humber. The Dove takes its rise among the hills in the moorlands, near the points where the counties of Stafford, Derby, and Chester meet. From the declivity of its channel, its waters flow with uncommon rapidity: in some places it dashes precipitately over rugged rocks; in others it is distinguished by gentle cascades. It falls into the Trent near Burton, on the confines of Derbyshire. The Tame, another river of considerable size, springs from several sources in the vicinity of Walsall and Colehill, enters Warwickshire near Birmingham, returns into Staffordshire at Tamworth, and finally joins the Trent. The Blythe rises in the neighbourhood of Watley moor, in the northern district. Its course is nearly parallel to the Trent, into which it falls near King's-Bromley.

Canals.—Although an inland situation, without navigable rivers, appears to labour under peculiar disadvantage for the purposes of trade; yet in Staffordshire the deficiency is amply compensated by the number and extent of the canals, with which this county is so largely supplied. The principal are the Grand Trunk Canal, the Coventry and Oxford, and the Birmingham Canal. These, with their numerous branches and ramifications, have already been particularly described. See CANALS.

Lakes and Springs.—This county affords but few lakes, and those of no great consequence. Those most worthy notice are that of Aquilate, which extends 1848 yards in length, and 672 in breadth; and Ladford Pool, which occupies the space of about 60 acres. Salt springs are found in various places. The most considerable are those in the parish of Weston, whence salt is produced, equal in quality and colour to that of any part of the kingdom.

Minerals.—The number and value of the mineral productions of Staffordshire claim particular notice. Coal is abundant: upwards of 50,000 acres have been ascertained to contain an inexhaustible supply, near enough to the surface to be easily raised. From the earliest times to the present, the consumption does not appear to have exceeded a tenth part of the whole. In the southern division of the county, the coal district extends in length from the interior

of Cannock-heath to the vicinity of Stourbridge, and in breadth from Wolverhampton to Walfall. To the north, likewise, it abounds in the neighbourhood of Newcastle and the Potteries, Lane-End, Hollybush, Cheadle, and Dill-horne. At Handley-Green a very peculiar species is dug, called the Peacock coal, from the prismatic colours it displays. Limestone is still more abundant than coal. At Sedgely and Dudley-castle hills, Rushall and Haywood, and on the north-east moorlands, the quantity is immense. The lime-works upon Caldon Low, and near the Wcever hills, are particularly extensive. This stone is, in some places, of a marble quality, and capable of taking a fine polish. In other parts it is chiefly composed of trematolith, or petrified marine substances of the animal kind. Iron ore is plentiful throughout the coal district. Near Wednesbury, Tipton, Bilston, and Sedgely, and to the west of Newcastle, it is peculiarly excellent and abundant. The strata are generally ranged beneath a stratum of coal. Iron-works of great extent have been recently established on the banks of the Birmingham Canal; and the trade is so rapidly increasing, as to afford a prospect of its precluding the necessity of any considerable importation. Copper and lead ore also abound in this county. A copper-mine is worked at Mixon, near Leek; but a more important one at Ecton-hill, near Warflow, on the estate of the duke of Devonshire. This hill has likewise a considerable vein of lead; and another of the same mineral has been found near Stanton-moor. In this part of the county, but particularly at Whiston, Oakmoor, and Cheadle, smelting and brass-works are carried on to a considerable extent. Quarries of good free-stone for various purposes are found in the different districts. A durable kind for building, easily raised in blocks of any dimension, is found at Tixal. Alabaster was formerly dug in great quantities, particularly on the banks of the Dove; but though it still exists in plenty, very few of the quarries are now wrought. This county also yields various kinds of marble: that species, to which the name of rance-marble is given, abounds on Yelperley Tor, and the adjacent hills. Clays of every denomination are abundant. Amblecot produces a clay of a dark-blue colour, of which are made the best glass-house pots of any in England. Glass-houses have, in consequence, been erected in the neighbourhood; and great quantities of the clay are sent to different parts of the kingdom. Potters' clay of various sorts is found here, particularly in the vicinity of Newcastle, where the potteries are chiefly carried on. Yellow and red ochre, and other earths used for colouring and painting, are among the productions of this county. At Darlaston, near Wednesbury, is a blue clay, which is sold to glovers to dye ash-colour. A black chalk is found in the beds of grey marble in Langley Clove; and under a rock near Hemley Hall is a reddish earth, nearly equal to the red chalk of France.

The farms of Staffordshire are of all extents, from fifty acres to five hundred; but the number of the smaller has been lately much diminished. The rent of land varies from 15s. to 40s. per acre, making the average about 25s. The cultivated lands of this county are nearly all inclosed, not more than 1000 acres still remaining open. The fences in the southern part are chiefly raised from quicksets, among which the white thorn is most approved.

Timber, Plantations, and Woodlands.—This county, notwithstanding the great recent consumption, is abundantly stocked with wood of every description. Lord Bagot's estate, near Abbot's-Bromley, contains several acres of oaks, not to be surpassed in quality by any in the kingdom: the timber in many of them is to the height of sixty or

seventy feet. Chillingworth estate ranks next to this for the value of its woods. Those at Beaufert, the seat of the earl of Uxbridge, and those at Llimley, the property of lord Dudley, are also very extensive. Teddesley has very considerable plantations. Mansley wood is a coppice of fine oak. Wrottesley, Fitherwick, Trentham park, Sandwell park, Enville, and Hilton, display abundance of well-grown trees of every description.

Waste Lands.—The extent of uncultivated lands in this county is very great; being computed by Mr. Pitt to amount to an hundred thousand acres. The chief waste districts in the southern parts are Cannock-heath and Sutton-Coldfield, with Swindon, Wombourn, and Fradley commons. In the north are Morredge, Wetley-moor, Stanton-moor, Hollington-heath, Carewell-common, and Needwood forest; which last, however, has been in part recently inclosed and cultivated.

Manufactures and Commerce.—Various branches of manufacture are carried on to a great extent, particularly in the southern parts of the county: the chief are hardware articles, nails, glass, toys, japanned goods, and potters' ware; with productions in cotton, silk, leather, woollen, and linen. The manufacture of glass is most considerable in the vicinity of Stourbridge, where many spacious glass-houses have been built. The potteries occupy an extent of ten miles, toward the north part of the county: these have acquired great reputation from the ingenious Mr. Wedgwood. (See POTTERIES.) Wolverhampton and the neighbouring villages are distinguished for the manufacture of locks: buckles, steel-toys, and watch-chains, are among the esteemed productions of that town. The staple manufacture of Walfall and its vicinity is chiefly shoe-buckles, clasps, and sadlers' ironmongery. Nail-making, in many country parishes, is a source of employment to great numbers of men, women, and children. Bilston furnishes a variety of plated, lackered, japanned, and enamelled goods. At Wednesbury the gun-trade is extensive. At Darlaston, Willenhall, and the adjacent villages, tobacco and snuff-boxes are wrought in various modes. Stafford and its neighbourhood exhibit numerous articles in the cutlery and leather-trade: the hat manufacture is also carried on there, and in some other towns, on an extensive scale. Tin and brass are among the common production of the county. The cotton manufactures at Rocceller, Fazeley, Tamworth, Burton, and Tutbury, are very considerable; as is likewise the silk-trade of Leek, and that of tape at Cheadle and Teyn. The woollen manufacture is but comparatively trifling; most of the raw wool being sold into the clothing and stocking districts. The making of linen is mostly confined to private families, for their own use.

It is worthy of observation, that the original wooden almanac of the Norwegians and Danes is still in use in this county, under the appellation of the Staffordshire clog. Engravings of this calendar, something different from each other, may be seen in Dr. Plot's Natural History of the County, and in Camden's Britannia, by Gough. The principal antiquities in this county are the cathedral at Lichfield; Tutbury castle and church; Dudley castle and priory; Eccleshall castle; Croxton abbey; Alton castle; Wolverhampton church; bridge and abbey, at Burton-upon-Trent; Darlaston castle; Tixal manor-house; Hilton abbey; Rowton priory; Uttoxeter church; Carewell castle; Chartley castle; Heyley castle.

Authorities.—History, &c. of Staffordshire, by the Rev. S. Shaw, 2 vols. folio, 1798, &c. an unfinished work. General View of the Agriculture of the County of Stafford, by William Pitt, 8vo. 1808. The Natural History

of Staffordshire, by Dr. Plot, fol. 1686. A Map of the County, begun in 1769, and finished in 1775, by William Gates, six sheets. Account of Staffordshire, in the Beauties of England, vol. xiii.

Starch

STARCH, a substance which is extracted from wheaten flour, by washing it in water. All farinaceous seeds, and the roots of most vegetables, afford this substance in a greater or less degree; but it is most easily obtained from the flour of wheat, by moistening any quantity thereof with a little water, and kneading it with the hand into a tough paste: this being washed with water, by letting fall upon it a very slender stream, the water will be rendered turbid as it runs off, in consequence of the fecula or starch which it extracts from the flour, and which will subside when the water is allowed to stand at rest. The residuum of the flour, which remains after the water has extracted all the fecula, and runs off colourless, will be found to be *gluten*; which see.

The starch so obtained, when dried in the sun, or by a stove, is usually concretioned into small masses of a long figure and columnar shape, which have a fine white colour, scarcely any smell, and very little taste. If kept dry, starch in this state continues a long time uninjured, although exposed to the air. It is not soluble in cold water; but forms a thick paste with boiling-hot water, and when this paste is allowed to cool, it becomes semitransparent and gelatinous, and being dried, becomes brittle, and somewhat resembles gum.

Starch, although found in all nutritive grains, is only perfect when they have attained maturity, for before this it is in a state approaching to mucilage, and so mixed with saccharine matter and essential oils, that it cannot be extracted in sufficient purity to concrete into masses.

Wheat, or such parts of it as are not used for human food, are usually employed for manufacturing starch, such as the refuse wheat and bran; but when the finest starch is required, good grain must be used. This, being well cleaned, and sometimes coarsely bruised, is put into wooden vessels full of water to ferment: to assist the fermentation, the vessels are exposed to the greatest heat of the sun, and the water is changed twice

a day, during eight or twelve days, according to the season. When the grain bursts easily under the finger, and gives out a milky white liquor when squeezed, it is judged to be sufficiently softened and fermented. In this state, the grains are taken out of the water by a sieve, and put into a canvas sack, and the husks are separated and rubbed off, by beating and rubbing the sack upon a plank: the sack is then put into a tub filled with cold water, and trodden or beaten till the water becomes milky and turbid, from the starch which it takes up from the grain. A scum sometimes swims upon the surface of the water, which must be carefully removed; the water is then run off through a fine sieve into a settling-vessel, and fresh water is poured upon the grains, two or three times, till it will not extract any more starch, or become coloured by the grain. The water in the settling-vessels being left at rest, precipitates the starch which it held suspended; and to get rid of the saccharine matter, which was also dissolved by the water, the vessels are exposed to the sun, which soon produces the acetous fermentation, and takes up such matter as renders the starch more pure and white. During this process, the starch for sale in the shops receives its colour, which consists of smalt mixed with water and a small quantity of alum, and is thoroughly incorporated with the starch; but this starch is unfit for medicinal purposes. When the water becomes completely four, it is poured gently off from the starch, which is washed several times afterwards with clean water, and at last is placed to drain upon linen cloths supported by hurdles, and the water drips through, leaving the starch upon the cloths, in which it is pressed or wrung, to extract as much as possible of the water; and the remainder is evaporated, by cutting the starch into pieces, which are laid up in airy places, upon a floor of plaster or of slightly burnt bricks, until it becomes completely dried from all moisture, partly by the access of

warm air, and partly by the floor imbibing the moisture. In winter-time, the heat of a stove must be employed to effect the drying. Lastly, the pieces of dried starch are scraped, to remove the outside crust, which makes inferior starch, and these pieces are broken into smaller pieces for sale.

The grain which remains in the sack after the starch is extracted, contains the husks and the glutinous part of the wheat, which are found very nutritious food for cattle.

The French manufacturers, according to *Les Arts et Metiers*, pursue a more economical method, as they are enabled, by employing an acid water for the fermentation in the first instance, to use the most inferior wheat, and the bran or husks of wheat. This water they prepare, by putting a pailful of warm water into a tub, with about two pounds of leaven, such as some bakers use to make their dough rise or ferment. The water stands two days, and is then stirred up, and half a pailful of warm water added to it; then being left to settle till it is clear, it is poured off for use. To use this water in the fermentation of the materials, a quantity of it is poured into a tub, and about as much fair water is poured upon it as will fill the tub half full: the remainder of the tub is then filled up with the materials, which are one half refuse wheat, and the other half bran. In this tub it continues to steep and ferment during ten days, or less, according to the strength of the leaven-water, and according to the disposition of the weather for fermentation. When the materials have been sufficiently steeped, or fermented, an unctuous matter, which is the oil of the grain, will be seen swimming on the surface, having been thrown up by the fermentation. This must be skimmed off; and the fermented grain, being taken out of the tub, is put into a fine hair-sieve, placed over a settling-tub, when fair water is poured upon it, and washed through the sieve into the tub; by which means the starch is carried through the sieve with the water, of which about six times the quantity of the grain are used.

The water stands in the settling-tub for a day, and becomes clear at top; when it is carefully laded out of the tub, leaving at the bottom a white sediment, which is the starch. The water which is taken off is four, and is called *sure water*: this is the proper leaven for the first steeping of the materials. The starch now obtained must be rendered marketable; for which purpose, as much water is poured upon it as will enable it to be pounded and broken up with a shovel, and then the tub is filled up with fair water. Two days after this, the water is laded out from the tub, and the starch appears in the bottom, but covered over with a dark-coloured and inferior kind of starch, which is taken off, and employed for fattening hogs. The remainder of the sediment, which is good starch, is washed several times, to remove all the inferior starch; and when this is done, about four inches of thick starch should be found at the bottom of each tub: but the quantity varies, according to the goodness of the meal or bran which has been used. It is evident that the refuse wheat, when employed for making starch, ought to afford more, the whole being used, than the bran or husks; but the starch so extracted is always of an inferior quality to that which is extracted from the bran of good wheat, particularly in the whiteness of its colour. The starch in the different tubs is brought together into one, and there worked up with as much water as will dissolve it into a thin paste, which is put into a silk sieve, and strained through with fresh water. This water is settled in a tub, and afterwards poured off, but before it is so completely settled as to lose all its white colour: this renders the starch which is deposited still finer and whiter, and the starch which is deposited by the water so poured off is of a more common quality.

The starch thus purified is taken out of the bottom of the tubs, and put into wicker-baskets, about 18 inches long and 10 deep, rounded at the corners, and lined with linen cloths, which are not fastened to the baskets. The water drips from the starch through the cloths for a day, and the baskets are then carried up to apartments at the top of the house, where the floor is made of very clean white plaster; and the windows are thrown open, to admit a current of air. Here the baskets are turned downwards upon the plaster-floor, and the linen cloths, not being fastened to the baskets, follow the starch, and, when taken off, leave loaves, or cakes of starch, which are left to dry a little, and are then broken into smaller pieces, and left on the plaster-floor till very dry. But if the weather is at all humid, the starch is removed from the plaster-floor, and spread out upon shelves, in an apartment which is warmed by a stove, and there it remains till perfectly dry. The pieces are afterwards scraped, to remove the outside crust, which makes common starch; and the scraped pieces being again broken small, the starch is carried to the stove, and spread out to a depth of three inches, on hurdles covered with cloths. The starch must be turned over every morning and evening, to prevent it from turning to a greenish colour, which it would otherwise do.

Those manufacturers who are not provided with a stove, make use of the top of a baker's oven to spread the starch upon; and after being thoroughly dried here, it is ready for sale.

Starch may be made from potatoes, by soaking them about an hour in water, and taking off their roots and fibres, then rubbing them quite clean by a strong brush: after this they are reduced to a pulp, by grating them in water. This pulp is to be collected in a tub, and mixed up with a large quantity of clear water: at the same time, another clean tub must be provided; and a hair-sieve, not too fine, must be supported over it by two wooden rails extended across the tub. The pulp and water are thrown into the sieve, and the flour or starch is carried through with the water; fresh water must then be poured on, till it runs through quite clear. The refuse pulp which remains in the sieve, being boiled in water, makes an excellent food for animals; and the quantity of this pulp is near seven-eighths of all the potatoes employed.

The liquor which has passed through the sieve is turbid, and of a darkish colour, from the extractive matter which is dissolved in it. When it is suffered to rest for five or six hours, all this matter deposits or settles to the bottom, and the liquor which remains is to be poured off as useless; and a large quantity of fresh water is thrown upon the flour, and stirred up: it is then settled for a day, and the water being poured off, the flour will be found to have again settled in a whiter state. But to improve it, another quantity of water is poured on, and mixed up with it; in which state it is passed through a fine silk-sieve, to arrest any small quantity of the pulp which may have escaped the first hair-sieve. The whole must afterwards be suffered to stand quiet, till the flour is entirely settled, and the water above become perfectly clear; but if the water has any sensible colour or taste, the flour must be washed again with fresh water, for it is absolutely necessary that none of the extractive matter be suffered to remain with it. The flour, when thus obtained pure, and drained from the water, may be taken out of the tub with a wooden shovel, and placed upon wicker-frames covered with paper, to be dried in some situation properly defended from dust.

When the manufacture of starch from potatoes is attempted in a large way, some kind of mill must be used to reduce

reduce them to a pulp, as the grating of them by hand is too tedious an operation. A mill invented by M. Baumé is very complete for this purpose. In its general structure it resembles a large coffee-mill: the grater consists of a cone of iron-plate, about seven inches in diameter, and eight inches in height, the exterior surface of which is made toothed, like a rasp, by piercing holes through the plate from the inside. This cone is fixed upon a vertical axle, with a handle at the top to turn it by; and is mounted on the pivots of the axle, within a hollow cylinder of plate-iron, toothed within like the outside of the cone; the smallest end of the interior cone being uppermost, and the lower or larger end being as large as the interior diameter of the hollow cylinder. A conical hopper is fixed to the hollow cylinder, round the top of it, into which the potatoes are thrown; and falling down into the space between the outside of the cone and the inside of the hollow cylinder, they are ground, and reduced to a pulp, when the interior cone is turned round by its handle; and as the lower part of the cone is fitted close to the interior diameter of the cylinder, the potatoes must be ground to a fine pulp before they can pass through between the two. The machine, when at work, is placed in a tub filled with water; and as fast as the grinding proceeds, the pulp mixes regularly with the water, ready for the process before described.

Mr. Whately of Cork has also proposed a mill for the same purpose, on a different plan. The grater is a cylinder, with its axis horizontal, and turned by a handle at one end, with a fly-wheel to regulate the motion. A hopper is placed over the cylinder, into which the potatoes are thrown, and are grated by resting upon the cylinder, as it revolves round. There is also an horizontal box opposite to the cylinder, into which the potatoes are received from the hopper, through a sliding-door; and a moveable end, which is fitted to the box, is pressed forwards towards the cylinder by a lever and weight, so as to force the potatoes contained in the box against the cylinder, which, being kept in constant motion, grates away the potatoes into a pulp with great rapidity, and it falls into a box beneath.

In the year 1796, lord William Murray obtained a patent for manufacturing starch from horse-chestnuts. The method was to take the horse-chestnuts out of the outward green prickly husk, and either by hand, with a knife or tool, or else with a mill adapted for the purpose, the brown rind was carefully removed, leaving the chestnuts perfectly white, and without the smallest speck. In this state the nuts were rasped or ground to a pulp with water, and the pulp washed with water through a coarse horse-hair sieve, and twice afterwards through finer sieves, with a constant addition of clear cold water, till all the starch was washed clean from the pulp which remained in the sieve; and the water being settled, deposited the starch, which was afterwards repeatedly washed, purified, and dried, in the same manner as the potatoe-starch before described. We are not informed if this manufacture has been carried into effect.

The four, nauseous, milky liquor obtained in the process of starch-making, appears, upon analysis, to contain acetous acid, ammonia, alcohol, gluten, and phosphate of lime. The office of the acid is to dissolve the gluten and phosphate of lime, and thus to separate them from the starch.

Starch is used along with smalt, or stone-blue, to stiffen and clear linen. The powder of it is also used to whiten and powder the hair.

It is also used by the dyers, to dispose their stuffs to take colours the better.

Starch is sometimes used instead of sugar-candy for mixing with the colours that are used in strong gum-water, to make them work more freely, and to prevent their cracking.

It is also used medicinally for the same intentions with the viscous substance which the flour of wheat forms with milk, in fluxes and catarrhs, under various forms of powders, mixtures, &c. A drachm of starch, with three ounces of any agreeable simple water, and a little sugar, compose an elegant jelly, of which a spoonful may be taken every hour or two. These gelatinous mixtures are likewise an useful injection in some diarrhoeas, particularly where the lower intestines have their natural mucus abraded by the flux, or are constantly irritated by the acrimony of the matter. Starch is the common vehicle for the exhibition of opium per anum.

By 43 Geo. III. c. 68. sched. (A), upon every hundred weight of starch imported a duty is imposed; and by 49 Geo. III. c. 98. sched. (A), a further duty upon every hundred weight is imposed.

No person shall be a maker of starch within the limits of the head-office of excise in London, unless he occupies a tenement of 10*l.* a year, or upwards, for which he shall be assessed in his own name, and also pay to the poor-rates; nor elsewhere, unless he pay to the church and poor; or if there are no such rates, to the rate on houses and windows, under the same penalty as for making starch without entry. (19 Geo. III. c. 40. s. 3. 26 Geo. III. c. 51. s. 20.) By 43 Geo. III. c. 69. sched. (A), every starch-maker shall take out a licence, for which he shall pay 5*l.*, and renew the same annually within ten days before the end of the year, on pain of 30*l.* 24 Geo. III. c. 41. sect. 2.

Places of making starch are to be entered, under penalty of 200*l.* (24 Geo. III. c. 48. sect. 2.) All rooms and places, vessels and utensils, shall be marked and numbered, on the penalty of 50*l.* (19 Geo. III. c. 40. s. 12.) Flour, and other materials, found in any private place, and all private utensils and vessels for making or keeping starch, unentered, shall be forfeited, or their value. (10 Ann. c. 26. s. 22.) Every starch-maker shall cause his name to be painted over his door, or on some conspicuous part of the front of his house, with the addition of *starch-maker*, on penalty of 100*l.* (24 Geo. III. c. 48. sect. 2.) Officers may at all times enter and survey, and make return to the commissioners, leaving a true copy of the quantity, if demanded, under his hand, with the maker; and if he leave not such copy, after it has been demanded in writing (12 Geo. I. c. 28.), he shall forfeit 40*l.* (10 Ann. c. 26. s. 14.) Notice of emptying the vats, and of taking the waters out of the tubs, shall be given, on pain of forfeiting 100*l.* (19 Geo. III. c. 40.) The maker shall use regular, square, or oblong boxes only, for boxing and draining his green starch, before it is dried in the stove, on pain of 10*l.*; and give notice of boxing, and an account of drying, &c. Nor shall he remove any starch after it is dried, before it be weighed, &c. by the officers, on pain of 200*l.* (4 Geo. II. c. 14. 19 Geo. III. c. 40.) All starch, before it be put into any stove or place to dry (except for crusting), shall be put in papers, tied up with strings, pasted over with a piece of paper of a different colour, and stamped by the officer, under penalty of 100*l.* (26 Geo. III. c. 51.) Forging or using forged stamps incurs a forfeiture of 500*l.* (26 Geo. III. c. 51.) The maker shall have just scales and weights, on pain of 10*l.*; and if he shall use insufficient scales or weights, he shall forfeit 100*l.* (10 Geo. III. c. 44.) Removing starch before due notice is prohibited by 10 Ann. c. 26. s. 19. And if it be removed before it is weighed by the officers, the person so offending shall forfeit 200*l.* (19 Geo. III. c. 40.) And if any dealer in starch shall receive more than 28 lbs. not duly marked, he shall forfeit 200*l.* 24 Geo. III. c. 48. 10 Ann. c. 26. s. 16.

Clandestine manufacture, or concealing of starch, exposes the party concerned, unless he can make it appear that the

duty has been paid, to a forfeiture of 50*l.*: and obstructing the officer in entering, seizing, &c. the same, incurs a forfeiture of 100*l.* (4 Geo. II. c. 14. 23 Geo. II. c. 21.) And by 19 Geo. III. c. 40. if the maker shall conceal any starch, with intent to defraud his majesty of the duties, he shall forfeit 100*l.* Weekly entry shall be made, on pain of 50*l.*; and the duties shall be cleared within one week after entry, on pain of double duty. No starch shall be imported, except in packages containing at least 224 lbs., on pain of forfeiture, and of 50*l.* from the matter of the vessel. (42 Geo. III. c. 93.) Starch that hath paid the duties may be exported with a drawback of the duties. (10 Ann. c. 26. 27 Geo. III. c. 13.) The officers of excise or customs may seize any starch or hair-powder, with the horse and package, suspected on good reason to have been privily made, or imported without payment of duty, or relanded after drawback; and if the party doth not make it appear that the duty hath been paid, they shall all be forfeited, with an additional forfeiture of 5*l.* for every hundred weight. (4 Geo. II. c. 14.) If any person shall knowingly harbour or conceal any starch unlawfully imported, or relanded after shipping for exportation upon debenture, he shall, whether he claim any property in it or not, forfeit 50*l.* for every hundred weight, together with the goods and package. (23 Geo. II. c. 21.) No perfumer, &c. shall make use of, or offer to sale, any hair-powder made of or mixed with alabaster, talc, plaster of Paris, whiting, lime, &c. (sweet scents only excepted), on pain of forfeiting the same, and 50*l.* (12 Ann. stat. 2. c. 9.) And if any maker of hair-powder shall mix any powder of alabaster, &c. (rice first made into starch, and sweet scents only excepted), he shall forfeit the same, and 50*l.* (12 Ann. stat. 2. c. 9.) Or if any one make or sell any made with such materials, he shall forfeit the same, and 20*l.* (4 Geo. II. c. 14.) Or if he shall have in his possession, for making, mixing, or counterfeiting hair-powder, any materials besides starch, or powder of starch, or rice made into starch, he shall forfeit the same, and 10*l.* Places for making hair-powder are to be entered, and officers may enter and survey them, under a penalty of 20*l.* 4 Geo. II. c. 14.

Every maker of stone-blue for sale shall make entry of his name, place of abode, place of manufacture and keeping, and materials, on pain of 50*l.* (26 Geo. III. c. 51.) Officers may enter and survey without obstruction, under penalty of 50*l.*: nor shall any flour, meal, or other ingredients (other than for colouring the same), be used, except starch for which the duties have been paid, on pain of forfeiting the same and 100*l.*

Nor shall any maker of stone-blue or hair-powder for sale receive into his possession any starch in papers not stamped, under pain of forfeiting 10*s.* a pound, together with the same: and if any maker shall keep above 28 lbs. of starch or hair-powder in any unentered place, the same shall be forfeited and also 50*l.* 26 Geo. III. c. 51.

All the preceding forfeitures shall be sued for, levied, and mitigated, as by the laws of excise, or in the courts at Westminster; and be distributed, half to the king and half to the prosecutor.

STARCHY Matter of Roots, Plants, and Seeds, in Rural Economy, is a material which forms a principal part of a great number of esculent articles of different kinds, upon which their nutrient properties and qualities probably in a great measure depend when used as the food of man, or employed in the feeding and fattening of several different kinds of domestic animals. See STARCH.

Thus, it is ascertained to exist in considerable quantities in the root of the potatoe and some other roots, in many different plants of the edible kind, and to constitute the

greatest part of most grains, pulse, and seeds which are employed as food. It is met with in a large proportion in the different nourishing vegetable substances which are known and made use of under the names of sago, salep, arrow-root, tapioca, cassava, and some others. In regard to the roots, plants, and perhaps seeds, derived from weeds, it is known to abound much in the root of *arum maculatum*, or wake robin, of the wild or English hyacinth, of white bryony, of meadow saffron, and of a variety of others. It is very predominant in numerous wild plants, and most probably in most of their seeds.

Sir Humphrey Davy conceives, that this matter or coagulated mucilage, which forms the greatest part of all grains and seeds which are used in the way of food, is generally combined with gluten, oil, or albuminous matter. In corn, with gluten; in pulse, such as peas and beans, with albuminous matter; and in rape-feed, lint-feed, hemp-feed, and the kernels of most nuts, with oils. He found that one hundred parts of good full-grained wheat sown in the autumn, afforded seventy parts of starch and nineteen parts of gluten: that one hundred parts of wheat sown in the spring yielded seventy of starch and twenty-four of gluten: that the same number of parts of Barbary wheat gave seventy-four of starch and twenty-eight of gluten: and that an equal number of parts of Sicilian wheat afforded seventy-five of starch and twenty-one of gluten. He has also tried different specimens of North American wheat, all of which have contained rather more gluten than those of British growth. In general, it is said, the wheat of warm climates abounds more in gluten and insoluble parts; and is of greater specific gravity, harder, and more difficult to grind, than that of others: and that the wheat of the south of Europe, in consequence of containing a larger proportion of gluten, is peculiarly fitted for making macaroni, and preparations of flour in which a glutinous quality is considered as an excellence.

In some trials made on barley, he obtained, from one hundred parts of a full, fair, Norfolk sort, seventy-nine of starch, six of gluten, and eight of husk; the remaining seven parts consisting of sweet or saccharine matter. The sugar in barley is suggested as probably the chief cause why it is more proper for malting than any of the other sorts of grain. It is stated that Einhoff, in his minute trials on barley-meal, found in three thousand eight hundred and forty parts, three hundred and sixty of volatile matter, forty-four of albumen, two hundred of saccharine matter, one hundred and seventy of mucilage, nine of phosphate of lime, with some albumen, one hundred and thirty-five of gluten, two hundred and sixty of husk, with some gluten and starch, two thousand five hundred and eighty of starch not quite free from gluten, and seventy-eight parts of loss in the whole. And that rye afforded to the same experimenter, in the same number of parts, two thousand five hundred and twenty of meal, nine hundred and thirty of husk, and three hundred and ninety of moisture: the same quantity of meal, on being analysed, gave two thousand three hundred and forty-five of starch, one hundred and twenty-six of albumen, four hundred and twenty-six of mucilage, one hundred and twenty-six of saccharine matter, and three hundred and sixty-four of gluten not dried. The remainder husk and loss.

The first of these writers obtained from one thousand parts of rye, which was grown in Suffolk, sixty-one parts of starch and five of gluten.

One hundred parts of oats, from Suffex, afforded him fifty-nine parts of starch, six of gluten, and two of saccharine matter.

One thousand parts of peas, grown in Norfolk, also afforded

ford: d him five hundred and one parts of starch, twenty-two of saccharine matter, thirty-five of albuminous matter, and sixteen parts of extract, which became insoluble during the evaporation of the saccharine fluid.

From three thousand eight hundred and forty parts of marsh beans, (*vicia faba*), the latter writer is stated to have obtained one thousand three hundred and twelve of starch, thirty-one of albumen, and one thousand two hundred and four of other matters which may be conceived to be nutritive; such as gummy, starchy, fibrous matter, analogous to animal matter.

The same quantity of kidney-beans (*phaseolus vulgaris*) is said to have afforded him, one thousand eight hundred and five parts of matter analogous to starch, eight hundred and fifty-one of albumen and matter, approaching to animal matter in its nature, and seven hundred and ninety-nine of mucilage.

From the same number of parts of lentils he is also stated to have obtained one thousand two hundred and sixty parts of starch, and one thousand four hundred and thirty-three of a matter analogous to animal matter, which is described as a glutinous substance insoluble in water; but soluble in alcohol when dry, having the appearance of glue; probably, it is supposed, a peculiar modification of gluten.

Different tuberos, bulbous, and common roots contain a large portion of starchy matter, but it probably abounds most in the potatoe. It is said that these roots in general afford from one-fifth to one-seventh of their weight of dry

starch. And that from one hundred parts of the common kidney potatoe Dr. Pearson obtained from twenty to twenty-three of starch and mucilage: the same number of parts of the apple potatoe afforded sir Humphrey Davy in various trials, from eighteen to twenty parts of pure starch. From five pounds of several other different varieties, in the trials of another experimenter, from twelve to eight ounces and a quarter of starch have been obtained. It is added, that from the analysis of Einhoff, it appears that seven thousand six hundred and eighty parts of potatoes afford one thousand one hundred and fifty-three of starch, five hundred and forty of fibrous matter analogous to starch, one hundred and seven of albumen, three hundred and twelve of mucilage in the state of a saturated solution: in the whole, two thousand one hundred and twelve parts. So that a fourth part of the weight of the potatoe at least may, it is said, be considered as nutritive matter. Hence its very great utility as an article of food for man, and its great application in the feeding and fattening of animals.

The propriety of encouraging the production of starch from useless roots, plants, and products, has been some time since suggested by Mr. Pitt in his Account of the Agriculture of Staffordshire, and which is said to equally apply to the preparation of this substance from any other vegetable which may not be a leading article of food, as well as to the production of hair-powder, paste, and other articles generally made from wheat.

Steam

STEAM, in a general sense, is a term used to signify the visible cloudiness arising from the condensation of aqueous vapour.

In those arts and manufactures where the vapour of water is employed, such as steam-engines, the term steam is used for water in its elastic form, at or above the temperature of 212° , and when it is invisible. It is in this form that we can properly call it steam; as we shall shew, that in the visible misty form in which we see it in the atmosphere, both in the form of clouds, and as it passes from a warm medium into a colder one, it is not steam but water in minute globules.

Some have confined the word steam to the vapour of water not less than 212° , as if water did not assume the elastic form at a lower temperature; conceiving it to exert the full force of steam the moment it arrives at that point, and to be wholly converted into water when reduced below the same. Nothing, however, can be more absurd than this notion: steam can exist at the lowest known temperature. At 50° below the cypher of Fahrenheit, if the barometer could shew it, the presence of ice would afford an elastic fluid of some force. We want no other proof of this fact than the experiments of different philosophers to ascertain the force of aqueous vapour, answering to different temperatures; and before we proceed further on our subject, it may not be amiss to give the table of these facts, formed by Mr. John Dalton of Manchester. In order to make these experiments, Mr. Dalton took a barometer of the common size. The mercury was first boiled, to free it from air. He then put a little water into the tube, and poured it out again, leaving its sides wet; and next introduced the mercury, inverting the tube so as to exclude the air. The water, being the lightest fluid, rose above the surface of the mercury about one-eighth of an inch. He then surrounded the tube, from the top downwards, with

another tube, 14 inches long and 2 inches diameter; forming a cavity between the tubes, capable of holding water of different temperatures. The temperature of this water was constantly marked by a thermometer placed in it; and the elasticity of the vapour, in the upper part of the barometer, was constantly marked by the height of the mercury. The outer tube being of glass, the whole could be seen. This apparatus was used for all the temperatures below 155° . For the higher temperatures, as high as 212° , he used an outer tube of tin, with a siphon barometer.

These results he found to agree with similar experiments made with the air-pump. The air-pump was provided with a mercurial gage of considerable extent. Some water was first made to boil in a Florence flask, in which a thermometer was placed. In this state it was put under the receiver, and then the air being withdrawn, the steam alone affected the barometer; the thermometer, at the same time, marking the temperature.

From these facts Mr. Dalton constructed his table. The altitudes of the mercury, answering to the degrees of temperature, he found not to have a constant ratio; nor did they vary by any regular progression. When the degrees were in arithmetical progression, the columns of mercury answering thereto were not in the same, but something approaching to a geometrical series. The increase, although not strictly geometrical, of the ratios themselves diminished regularly, which enabled him to calculate with sufficient exactness those degrees which he could not ascertain by experiment. We seldom find any of nature's laws attended with any thing so indefinite; and Mr. Dalton very properly observes, that the defect is not in nature, but in the imperfect scale of our thermometers, which, M. de Luc and others have shewn, do not mark equal increments of heat.

TABLE of the Force of Vapour from Water in every Temperature, from that of the Congelation of Mercury, or 40° below Zero of Fahrenheit, to 325°.

Tempera- ture.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Tempera- ture.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Tempera- ture.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.
-40°	.013	.1096	49	.363	3.061	104	2.11	17.79
-30	.020	.1686	50	.375	3.162	105	2.18	18.79
-20	.030	.2530	51	.388	3.238	106	2.25	18.97
-10	.043	.3626	52	.401	3.457	107	2.32	19.55
0	.064	.5397	53	.415	3.499	108	2.39	20.15
1	.066	.5566	54	.429	3.617	109	2.46	20.74
2	.068	.5734	55	.443	3.735	110	2.53	21.33
3	.071	.5987	56	.458	3.862	111	2.60	21.92
4	.074	.6274	57	.474	3.997	112	2.68	22.26
5	.076	.6409	58	.490	4.130	113	2.76	23.24
6	.079	.6666	59	.507	4.242	114	2.84	23.95
7	.082	.6915	60	.524	4.419	115	2.92	24.39
8	.085	.7168	61	.542	4.540	116	3.00	25.30
9	.087	.7337	62	.560	4.722	117	3.08	25.97
10	.090	.7590	63	.578	4.874	118	3.16	26.31
11	.093	.7843	64	.597	5.034	119	3.25	27.40
12	.096	.8096	65	.616	5.194	120	3.33	28.08
13	.100	.8433	66	.635	5.355	121	3.42	28.84
14	.104	.8773	67	.655	5.523	122	3.50	29.51
15	.108	.9114	68	.676	5.700	123	3.59	21.17
16	.112	.9445	69	.698	5.886	124	3.69	31.11
17	.116	.9782	70	.721	6.080	125	3.79	31.99
18	.120	1.120	71	.745	6.282	126	3.89	32.80
19	.124	1.457	72	.770	6.493	127	4.00	33.73
20	.129	1.878	73	.796	6.712	128	4.11	34.66
21	.134	1.130	74	.823	6.940	129	4.22	35.58
22	.139	1.172	75	.851	7.176	130	4.34	36.58
23	.144	1.214	76	.880	7.421	131	4.47	37.69
24	.150	1.265	77	.910	7.677	132	4.60	38.79
25	.156	1.315	78	.940	7.994	133	4.73	39.88
26	.162	1.366	79	.971	8.188	134	4.86	40.98
27	.168	1.416	80	1.00	8.466	135	5.00	42.16
28	.174	1.467	81	1.04	8.770	136	5.14	43.34
29	.180	1.518	82	1.07	9.023	137	5.29	44.61
30	.186	1.568	83	1.10	9.276	138	5.44	45.87
31	.193	1.620	84	1.14	9.614	139	5.59	47.14
			85	1.17	9.867	140	5.74	48.40
			86	1.21	10.20	141	5.90	49.75
3	.200	1.686	87	1.24	10.45	142	6.05	50.31
33	.207	1.745	88	1.28	10.79	143	6.21	51.37
34	.214	1.804	89	1.32	11.13	144	6.37	53.72
35	.221	1.863	90	1.36	11.46	145	6.53	55.06
36	.229	1.931	91	1.40	11.80	146	6.70	56.53
37	.237	1.998	92	1.44	12.14	147	6.87	57.33
38	.245	2.066	93	1.48	12.48	148	7.05	59.45
39	.254	2.142	94	1.53	12.90	149	7.23	60.97
40	.263	2.217	95	1.58	13.32	150	7.42	62.57
41	.273	2.302	96	1.63	13.75	151	7.61	64.17
42	.283	2.353	97	1.68	14.16	152	7.81	65.86
43	.294	2.479	98	1.74	14.68	153	8.01	67.55
44	.305	2.572	99	1.80	15.18	154	8.20	69.15
45	.316	2.664	100	1.86	15.68	155	8.40	70.84
46	.328	2.762	101	1.92	16.19	156	8.60	72.52
47	.339	2.858	102	1.98	16.69	157	8.81	74.29
48	.351	2.960	103	2.04	17.20	158	9.02	76.06

TABLE—continued.

Tempera- ture.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Tempera- ture.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Tempera- ture.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.
159	9.24	77.72	214	31.21	263.20	270	77.85	656.53
160	9.46	79.77	215	31.83	267.39	271	78.89	665.30
161	9.68	82.63	216	32.46	272.74	272	79.94	674.16
162	9.91	83.57	217	33.09	275.72	273	80.98	682.93
163	10.15	84.45	218	33.72	284.37	274	82.10	692.37
164	10.41	88.04	219	34.35	289.68	275	83.13	701.06
165	10.68	90.07	220	34.99	298.88	276	84.35	711.38
166	10.96	91.76	221	35.63	300.81	277	85.47	720.79
167	11.25	94.87	222	36.25	305.70	278	86.50	729.48
168	11.54	97.32	223	36.88	311.02	279	87.63	739.01
169	11.83	99.76	224	37.53	316.50	280	88.75	748.45
170	12.13	102.96	225	38.20	322.15	281	89.87	757.90
171	12.43	104.45	226	38.89	327.63	282	90.99	767.34
172	12.73	107.34	227	39.59	336.87	283	92.11	776.97
173	13.02	109.73	228	40.30	339.86	284	93.23	786.23
174	13.32	112.32	229	41.02	345.93	285	94.35	795.68
175	13.62	114.52	230	41.75	352.09	286	95.48	805.21
176	13.92	117.39	231	42.49	358.33	287	96.64	814.99
177	14.22	126.58	232	43.24	364.65	288	97.80	824.78
178	14.52	122.45	233	44.00	371.06	289	98.96	834.56
179	14.83	126.06	234	44.78	377.64	290	100.12	844.34
180	15.15	127.76	235	45.58	384.39	291	101.28	854.12
181	15.50	130.71	236	46.39	391.22	292	102.45	863.99
182	15.86	133.75	237	47.20	398.05	293	103.63	873.94
183	16.23	136.87	238	48.02	404.96	294	104.80	883.81
184	16.61	141.41	239	48.84	411.88	295	105.97	893.68
185	17.00	143.36	240	49.67	418.88	296	107.14	903.54
186	17.40	145.17	241	50.50	425.18	297	108.31	913.41
187	17.80	148.51	242	51.34	432.96	298	109.48	923.28
188	18.20	153.48	243	52.18	440.05	299	110.64	933.06
189	18.60	156.86	244	53.03	447.21	300	111.81	942.93
190	19.00	160.23	245	53.88	454.38	301	112.98	952.79
191	19.42	163.77	246	54.68	461.13	302	114.15	962.99
192	19.86	167.48	247	55.64	468.35	303	115.32	972.53
193	20.32	171.36	248	56.42	476.26	304	116.50	982.15
194	20.77	175.16	249	57.31	482.98	305	117.68	992.43
195	21.22	178.95	250	58.21	490.90	306	118.86	1002.38
196	21.68	182.83	251	59.12	491.91	307	120.03	1014.53
197	22.13	186.62	252	60.05	506.42	308	121.20	1020.12
198	22.69	186.62	253	61.00	514.43	309	122.37	1034.98
199	23.16	195.98	254	61.92	522.19	310	123.53	1041.76
200	23.64	199.36	255	62.85	530.33	311	124.69	1051.55
201	24.12	203.41	256	63.76	537.70	312	125.85	1061.36
202	24.61	207.54	257	64.82	579.98	313	127.00	1071.03
203	25.10	211.67	258	65.78	554.74	314	128.15	1080.73
204	25.61	219.31	259	66.75	562.92	315	129.29	1090.24
205	26.13	220.36	260	67.73	571.18	316	130.43	1099.95
206	26.66	224.83	261	68.72	579.53	317	131.57	1109.57
207	27.20	229.38	262	69.72	587.97	318	132.72	1119.27
208	27.74	233.94	263	70.73	596.48	319	133.86	1125.55
209	28.20	237.82	264	71.74	605.00	320	135.00	1138.50
210	28.84	243.21	265	72.76	603.60	321	136.14	1148.11
211	29.41	248.02	266	73.77	617.06	322	137.28	1157.72
212	30.00	253.00	267	74.79	670.72	323	138.42	1167.34
			268	75.80	679.24	324	139.56	1176.95
213	30.60	258.06	269	76.82	647.84	325	140.70	1186.57

In answer to some references which may be required, we have thought proper to add a third column to this table, shewing the weight of aqueous vapour contained in a cubic foot of space, when a sufficient quantity of water is present at the given temperature. This column has been formed on the fact, that when the force of vapour is 30 inches, the aqueous vapour in a cubic foot of space is equal to 253 grains. And since the density must be as the pressure; therefore, as 30 inches is to 253 grains, so is the force of vapour of any other degree to the number of grains in the cubic foot at the same.

This table, from 30° to 212° , was the result of careful experiment. Those below and above were determined by calculation, and will doubtless be much more correct than by experiment, from the great difficulty and uncertainty which the high and low temperatures would occasion. For a more detailed account of Mr. Dalton's experiments, see the *Manchester Transactions*, vol. v., and *Nicholson's Journal*, vols. vi. and vii.

There will be found a valuable reference in all practical applications of steam, and will not be of less importance in assisting any inquiry into the process of evaporation, as connected with the arts of life, and the natural evaporation in the air. With a view to assist our conception of the nature of steam, or of the elastic vapour of water, we shall condense a number of facts, which may be very proper to commit to memory.

1. A cubic inch of water forms a cubic foot of steam, when its elasticity is equal to 30 inches of mercury.

2. One pound of Newcastle coal converts seven pounds of boiling water into steam.

3. The time required to convert a given quantity of boiling water into steam, is six times that required to raise it from the freezing to the boiling point, or from 32° to 212° , supposing the supply of heat to be uniform.

4. When a quantity of water is exposed to a given temperature, the quantity of steam formed in a given time will be as the surface, all other things being equal. The quantity will also be jointly as the force of vapour answering to each degree of heat, and the surface.

The depth of water evaporated, in a given time, will be as the force of vapour, whatever the surface, if the mass be uniformly of the same temperature.

When the force of vapour is 30 inches, and the temperature at 212° , this degree being just preserved only, the depth evaporated is 1.3 inch in one hour. This will be near the truth for this temperature. For lower temperatures, the rules given with the table will point it out.

5. When a quantity of water is raised to the boiling point, or 212° , it requires as much heat to give it the elastic form as would raise the same water 900° higher. If its volume were not changed by the heat, that is, if it could be prevented from expanding, its temperature would become 1112° , with the same quantity of caloric. Thus, agreeably to fact the 3d, the heat required to convert water of 212° into steam, is six times that required to raise the temperature from 32° to 212° .

6. The same weight of water, in the form of steam, contains the same quantity of heat, whatever may be its temperature or density; that is, the temperature at which the steam is formed, added to the degrees required to give it the elastic form, is always a constant quantity. The meaning of this is, that if a given weight of aqueous vapour, at 100° for instance, were compressed till its elasticity became equal to that at 212° , no heat being allowed to escape, its temperature would become 212° by the condensation; and

it would, of course, contain the same heat as steam formed at the same temperature, viz. $212 + 900$, as mentioned in the last fact.

In viewing the second column of the table, and comparing it with the temperature in the first column, we shall be far from concluding that all the steam in the cylinder of a steam-engine is condensed by the best means employed. Owing to the circumstance of the rapid decrease of the force of vapour from the boiling point, some have been led to imagine that there is no medium between steam at 212° and liquid water. By referring to the table, we shall see that, by a decrease of temperature from 212° to 180° , the column of 30 inches is reduced to 15. This column is again bisected or reduced to 7.5, by the temperature falling to $150^{\circ}.5$. At $124^{\circ}.5$, the steam exerts a force equal to 3.75 inches of mercury; and this will be reduced to 1.875, at the temperature of $100^{\circ}.5$.

We here see the importance of Mr. Watt's discovery of condensing his steam in a separate vessel. The spring of the residual vapour in his cylinder, after condensation, is only equal to the force of vapour answering to the temperature of his condenser, while the cylinder itself is kept at 212° nearly.

In the old method of condensing in the cylinder, so much cold water would be added as would reduce the temperature as low as Mr. Watt's condenser, in order to produce as perfect a vacuum; and on filling the cylinder again the next time, it would require to be raised to its original heat, at the expence of fresh steam. The effect of cold water in condensing steam, whether in the cylinder or a separate vessel, may be easily known by calculation, and the aid of the preceding table.

Let C = the capacity of the vessel containing steam in cubic feet.

S = the weight of a cubic foot of steam.

q = the weight of condensing water.

T = its temperature.

b = the degrees of heat to convert water into steam.

d = the temperature of the steam.

t = the resulting temperature, supposing b and d to be sensible heat before the experiment, and t the same afterwards.

n = capacity of steam for heat, water being 1.

Then, according to a theorem for finding the resulting temperature by mixing bodies of different temperatures together,

$$t = \frac{qT + (b + d)CSn}{q + CSn}; \quad t, \text{ in this, will come}$$

out as if the steam in the vessel, after mixture, were condensed into water; when, in fact, the heat is divided between the remaining steam and the water, one part giving the whole a common temperature, and the other in a latent form giving elasticity to the vapour. But, according to fact the 6th, as before given, this steam contains as much heat above its own temperature as would raise it to 1112° ; hence the real temperature added to the latent heat will be equal t .

The conclusion from these facts will be, that $\frac{b + d}{t}$ will

be nearly in the same ratio with the density of the steam, before and after condensation, and, therefore, as the respective force of vapour. If p be the force of vapour of the steam before the experiment, and f that after condensation; then $\frac{b + d}{t} = \frac{p}{f}$, and $f = \frac{pt}{b + d}$. If we

now refer to the table with this force of vapour, we shall find the temperature after condensation. To illustrate this theorem by an example,

Let $C = 1$ cubic foot.

$S = 253$ grains, the weight of a cubic foot of steam.

$q = 253$ grains of water.

$t = 60$.

$h = 900$.

$d = 212$.

$$t = \frac{qT + (b+d)SCn}{q + CSn} = \frac{253 \times 60 + (900 + 212) \times 253 \times 9}{253 + 253 \times 9} = 558.$$

Then $\frac{b+d}{t} = \frac{p}{f}$, or $\frac{1112}{558} = \frac{30}{f} \therefore f = 15$ inches

of mercury. Now, the temperature answering to this force of vapour, in the table, is equal to $177^{\circ}.5$. The quantity of steam of this density will be as p to f ; therefore, as $30 : 15 :: 253 : 126.5$ grains: hence the whole weight, which was $558 - 126.5 = 431.3$ grains, the weight of water. Hence, if the capacity of the steam-vessel be known, and the degree of condensation at the same time be given, the supply of cold water for that purpose may be

ascertained. This will be $q = \frac{b+d-t}{t-T} CSn$.

We have before hinted at the vulgar idea of there being no medium between steam at 212° and liquid water. A doctrine strongly favourable to such an opinion is at present held by several philosophers of eminence. The elastic form of water, at all temperatures below 212° , is supposed to be a solution of water in air. Does any thing like this appear to be the case in the detail of Mr. Dalton's experiments, to determine the force of vapour of steam at different temperatures? We would ask, where was the air to dissolve the water above the column of mercury, in which water and mercury alone existed? It is admitted on all hands, that steam at 212° can exist independent of air; and where have we become acquainted with any rule, that aqueous vapour cannot exist in a separate state at other temperatures? This is certainly the case with respect to water; and it is highly probable, that a portion of all the solid and liquid matter on the globe exists in the elastic form, in proportion to the temperature. What is the smell we perceive from melted metals, and at a much lower temperature with some of the metals? This is very conspicuously observed in heating copper-plates and sheet-lead. The odour of cast-iron is particularly striking.

There can be no doubt that elastic mercury exists in the space above the mercury in a barometer, since the condensed mercury is seen frequently to coat the interior surface.

These appearances would be oftener observed, if it were not for the difficulty with which evaporation takes place, from the body affording the vapour being surrounded with vapour of its own and others. The presence of any elastic fluid mechanically resists further evaporation, to a degree more than is conceived. If water be exposed to a vacuum, a quantity of vapour depending upon the temperature would in a little time occupy the space; the first portion would project itself with great rapidity, and the last very slowly. The temperature being raised, would cause successive portions to rise, the limit being what we have shewn in the table. If

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at any temperature the vapour, already suspended over the water, be removed by a current or by an air-pump, the process would be greatly facilitated, as we observe in the drying of the ground in a brisk wind. This shews that the vapour of water resists evaporation more than the air itself; perhaps in the same medium, its retarding power increases as the density. The advocates for the solution of water in air have said, that the capacity of air for moisture is inversely as the density, whether this difference of density arises from the nature of the gas, or from rarefaction. It ought very properly to be asked, at what degree of rarefaction is the dissolved water a maximum? The most probable answer would be, at the limit of rarefaction. This is contrary to all laws of solution. If air can chemically combine with water, every particle of air may combine with a particle of water; and the quantity of water in a given space would be the greatest, when the air was the densest. If we had no direct proof that a given space will contain the same quantity of water, whether air be present or not, the hypothesis of the chemical solution of water in air could not be defended.

We have seen that the quantity of water in a given space is as the force of vapour in inches of mercury, because the density must be as the pressure. Mr. Dalton has ascertained by experiment, that the rate of evaporation, at a given temperature, is as the force of vapour at the same. See Nicholson's Journal, vol. vii. p. 5.

This fact leads to the conclusion, that since the density is also as the force of vapour, the velocity of dispersion through the air is the same at all temperatures. Since, however, the atmosphere always contains some moisture, the neat evaporating power will be as the difference between that force of vapour answering to the temperature at which dew would begin to fall, and the temperature to which the evaporating substance is exposed. That point in the atmosphere when dew falls, is called by Mr. Dalton the *dew-point*. The manner of finding this is as follows: Take a tall cylindrical bottle, about one foot high and three inches in diameter; or, if this is not at hand, a common decanter. Fill it with water so much colder than the air, that the bottle may appear misty, when it is put into it. If no appearance of this mist is observed, the water is not cold enough; and ice, or some freezing mixture, must be added to it. The bottle, when filled, must contain a thermometer. When the dew appears upon it, wipe it off with a clean dry cloth; and continue to do so till no more dew appears. Then observe at what degree the thermometer stands in the bottle, which will never be greater than the temperature of the air, which must also be noted. Then find in the table the force of vapour at the temperature of the dew-point, and also the force of vapour answering to the temperature of the atmosphere, or that of the mass which is the source of the vapour. The difference between these two columns of mercury will be expressive of the rate of evaporation.

In order to obtain absolute data for these processes, we shall make use of Mr. Dalton's facts, which were derived from careful and judicious experiments. He exposed water to different temperatures, to observe the weight evaporated in a given time. These vessels were of a cylindric form, one being $3\frac{1}{2}$ inches in diameter, and the other six inches. The lesser vessel, when the water in it was just made to boil, lost from 35 to 45 grains per minute; this difference being occasioned by a greater or lesser current of air passing over it. The quantities evaporated at different temperatures were found to agree exactly with the force of vapour.

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From a vessel of six inches in diameter, he found that at 212° the mean quantity evaporated in one minute was 154 grains. Then since the mean of the small vessel was about 40, if the quantity be as the surface, we ought to have $\frac{154}{40} = \frac{(6)^2}{(3.25)^2}$, which is very near; for if the small vessel

had been 3.05, then the two squares would have been in the ratio of $\frac{154}{40}$.

Mr. Dalton has constructed a table on these data, which, from its great utility in all inquiries relating to the moisture in the atmosphere, cannot fail to be acceptable.

TABLE, shewing the Force of Vapour, and the full evaporating Force for every Degree of Temperature from 20° to 85° , expressed in Grains of Water raised *per Minute*, supposing no Moisture in the Atmosphere at the Time.

Temp.	Force of Vapour.	Evaporating Force in Grains per Minute.			Temp.	Force of Vapour.	Evaporating Force in Grains per Minute.		
		Lesser Extreme.	Mean.	Greater Extreme.			Lesser Extreme.	Mean.	Greater Extreme.
212°	30	120	154	189					
20	.129	.52	.67	.82	53°	.415	1.66	2.13	2.61
21	.134	.54	.69	.86	54	.429	1.71	2.20	2.69
22	.139	.56	.71	.88	55	.443	1.77	2.28	2.78
23	.144	.58	.73	.91	56	.458	1.83	2.35	2.88
24	.150	.60	.77	.94	57	.474	1.90	2.43	2.98
25	.156	.62	.79	.97	58	.490	1.96	2.52	3.08
26	.162	.65	.82	1.02	59	.507	2.03	2.61	3.19
27	.168	.67	.86	1.05	60	.524	2.10	2.70	3.30
28	.174	.70	.90	1.10	61	.542	2.17	2.79	3.41
29	.180	.72	.93	1.13	62	.560	2.24	2.88	3.52
30	.186	.74	.95	1.17	63	.578	2.31	2.97	3.63
31	.193	.77	.99	1.21	64	.597	2.39	3.07	3.76
32	.200	.80	1.03	1.26	65	.616	2.46	3.16	3.87
33	.207	.83	1.07	1.30	66	.635	2.54	3.27	3.99
34	.214	.86	1.11	1.35	67	.655	2.62	3.37	4.12
35	.221	.90	1.14	1.39	68	.676	2.70	3.47	4.24
36	.229	.92	1.18	1.45	69	.698	2.79	3.59	4.38
37	.237	.95	1.22	1.49	70	.721	2.88	3.70	4.53
38	.245	.98	1.26	1.54	71	.745	2.98	3.83	4.68
39	.254	1.02	1.31	1.60	72	.770	3.08	3.96	4.84
40	.263	1.05	1.35	1.65	73	.796	3.18	4.09	5.00
41	.273	1.09	1.40	1.71	74	.823	3.29	4.23	5.17
42	.283	1.13	1.45	1.78	75	.851	3.40	4.37	5.34
43	.294	1.18	1.51	1.85	76	.880	3.52	4.52	5.53
44	.305	1.22	1.57	1.92	77	.910	3.65	4.68	5.72
45	.316	1.26	1.62	1.99	78	.940	3.76	4.83	5.91
46	.327	1.31	1.68	2.06	79	.971	3.83	4.99	6.10
47	.339	1.36	1.75	2.13	80	1.00	4.00	5.14	6.29
48	.351	1.40	1.80	2.20	81	.04	4.16	5.35	6.54
49	.363	1.45	1.86	2.28	82	.07	4.28	5.50	6.73
50	.375	1.50	1.92	2.36	83	.10	4.40	5.66	6.91
51	.388	1.55	1.99	2.44	84	.14	4.56	5.86	7.17
52	.401	1.60	2.06	2.51	85	.17	4.68	6.07	7.40

In order to apply this table to practice, in finding the rate of evaporation at any time, suppose the dew-point found, as above directed, to be 45° , and the temperature of the air at the same time 70° . We find in this table, that the mean rate of evaporation at 45° is 1.62 grains in a minute; the rate at 70° 3.72. Then $3.7 - 1.62 = 2.08$ grains, the quantity evaporated in a minute, under such circumstances. If the example were to ascertain the rate of any artificial evaporation, the temperature of the mass exposed must be taken, instead of the temperature of the air. It must also be observed, that if a brisk wind prevails, the grains evaporated must be taken from the column marked "greater extreme." If there be no wind, look at

the "lesser extreme" column; and in a moderate breeze, take the "mean" column. By this means we are enabled to ascertain, at any time, not only the rate of evaporation, but the quantity of water contained in a cubic foot of space.

From the decrease of temperature in the upper regions of the atmosphere, and the greater decrease of the force of vapour at those temperatures, the greatest parts of the water which rises from the earth will be precipitated at a very small height.

If the temperature were taken by a thermometer, the degrees of which should shew equal increments of heat, aqueous vapour at any temperature would become of half this density,

fity, by a decrease of temperature equal to 25° . And since, at the intervals of every six miles above the surface of the earth, the pressure, and of course the force of vapour, is halved; the quantity of water in a cubic foot of space must diminish very fast with the height. At the temperature of 50° , when the atmosphere contains as much moisture as the temperature will admit, it contains only 3.5 grains in a cubic foot; and if the temperature upward were to vary no more than 25° for every six miles, at 20 miles high there would be little more than one grain of water in a cubic foot of space. But the temperature is known to vary much more rapidly; and hence we should have much less water in the same space, on account of the condensation resulting from this greater decrease. Still, however, some portion of water must exist in the very limits of our atmosphere, in a state of steam or vapour of some density; and this vapour is still within the limits of fact the 5th, before given, *viz.* If such vapour were compressed till its density was equal to 253 grains in the cubic foot, its temperature would be 212° , whatever might be its temperature previous to its compression. The same thing, as Mr. Dalton has very ingeniously supposed, would be the case with the air itself; that is, if the rarest part of our atmosphere were condensed to the density of that at the surface, its temperature would also become the same. This change of temperature in elastic fluids, by rarefaction or condensation, is evidently owing to a change in their specific heat. We have lately heard of a fact, which has excited the curiosity of some philosophers, and surprised others, which is as follows. When steam, of very considerable density from pressure, is made to issue from the mouth of a pipe, a person may place his finger close to the aperture, without feeling any unpleasant effect from the heat. The sensible heat of this steam, which would otherwise act, is absorbed by the sudden change of specific heat, by the expansion of the steam. This fact is very analogous to an experiment which has been long known. When the bulb of a thermometer is placed within the nozzle of a pair of bellows, and a blast sent through them, the mercury rises above the common temperature; but if the bulb be placed at a little distance from the nozzle, the mercury falls below the common temperature. In the first instance, the air was compressed, and the heat given out; in the second, heat was absorbed, and consequently the temperature lowered. The cold produced by the exhaustion of the receiver of the air-pump is to be explained in the same way.

The change of temperature of the atmosphere is doubtless more regular at considerable elevations, than near the surface: hence the air in which we live is frequently in a strong evaporating state, while condensation is taking place in the superior regions. This gives rise to numerous clouds, which are nothing more than water in small globules, having lost their elastic form by condensation. The changes of temperature, which take place from the various currents arising from the action of the sun upon the earth, materially and constantly change these appearances; sometimes causing the disappearance of opaque clouds, and at other times darkening the air by sudden condensation. We can but, therefore, regard the water in the air as existing in two states, namely, in the liquid and in the elastic state, between which there can be no medium: for evaporation or condensation must be the result of the slightest change of temperature; at least we may conclude, that one of these processes will commence with the change, and will progressively go on till as much water is either precipitated or taken up as the temperature will admit. Evaporation, as

we have before observed, can never be instantaneous: even if the air did not mechanically resist it, the presence of the vapour already formed would have that effect. Although there appears to be no medium between water and steam, the actual precipitation of the water is progressive, and is more or less rapid at different times. The clouds which appear to be suspended in the atmosphere are constituted by an assemblage of small globules of real water, which in vacuo would be precipitated with a rapidity agreeing with the laws of falling bodies; but in consequence of the resistance of air, their descent is retarded, being dependent upon the ratio between their surface and solidity.

There are good reasons for supposing that these globules are prevented from uniting by the presence of electricity, as we know that they must repel one another when they are similarly electrified. On the contrary, when particles are intermixed having contrary states of electricity, the condensation will be much facilitated, as we perceive in rain immediately succeeding thunder.

In all those situations where steam undergoes condensation, we do not see water immediately precipitated. The misty appearance is caused by small globules of real water falling towards the earth with a small but progressive velocity. If the change of temperature causing the condensation be very slow, the globules are extremely small in the first instance, and are with more difficulty united. This is doubtless the case with all bodies which are perfect liquids. Globules of mercury are united with greater difficulty the smaller they are. The state in which mercury exists in lard in the form of unction, is in these minute globules produced by the mechanical action in mixing it. If boiling water be poured upon mercurial ointment, the fat is separated and floats upon the water: this may be poured off, and the mercury will be left in minute globules, which are united with great difficulty. It occupies a much greater space than when united, having the appearance of froth. Such is the state of water forming the white fleecy clouds which we frequently observe at a great height; the dense dark-coloured clouds being composed of larger globules which seldom remain long before they are more completely formed into drops of rain.

The clouds, therefore, are not to be considered as absolutely suspended, but as water in globules of different magnitudes, falling with a velocity in the inverse ratio of their magnitudes. There is nothing hypothetical in this idea, since it is within the limits of calculation to ascertain the magnitude even of particles of lead falling through any assignable space in a given time. We cannot demonstrate the principle better than by solving the following problem.

What must be the diameter of a globule of water, to be capable of falling one inch in a second, after it has acquired an uniform velocity.

Let c = the specific gravity of the air through which the steam falls, water being 1.

p = 3.1416, &c.

g = the space a body falls in one second by gravity.

v = the velocity.

x = the diameter of the globule which is required.

Then, since the particle will cease to be accelerated when the resistance is equal to its weight, the velocity at that point will be v , which it will uniformly retain; all other things remaining equal. The space fallen through to give v ,

will be $\frac{v^2}{2g}$: this, multiplied by $\frac{p x^2}{4}$, will give $\frac{p v^2 x^2}{8g}$, the

content of the cylinder of air; and $\frac{c p v^2 x^2}{8g}$ = the weight

of the cylinder. This would be equal to the resistance, if the surface presented to the resisting medium had been a plane perpendicular to the direction. The resistance of such a surface to that of the spherical one, is as 1 to 2.

Hence the resistance will be $\frac{c p v^2 x^2}{16g}$.

The weight of a globule of water of the diameter a , will be $\frac{1}{6} \cdot p x^3 = \frac{c p v^2 x^2}{16g} \therefore = \frac{3}{8} \cdot \frac{c p v^2}{g}$. Then, since

$v = 1$ inch, $g = 194$ inches $= .0018$, $p = 3.1416$,

$\therefore x = \frac{3}{8} \times 1 \times \frac{1}{194} \cdot 0.0018 \times 3.1416 =$

$\frac{3 \times .0018 \times 3.1416}{8 \times 194} = .00001093$ of an inch, and in weight

only .00000000000027 of a grain.

When we consider how inconceivably small the atoms of water must be, it will be easy to conceive globules of water much smaller than the above calculation gives.

We are quite aware of the difficulties attendant on the best theory of clouds and rain. If the view we have given is supported by facts and observation, which at present appears to be the case, we may expect it to stand on firmer grounds than has hitherto been the fate of numerous hypotheses, as it is free from any thing gratuitous or hypothetical.

Steam is at present applied to many economical purposes, as well as in various manufactures, independent of its important office in the steam engine.

In dyeing, bleaching, and many other similar departments, it is used to communicate heat to water, instead of having separate fire-places and boilers. The vessels to contain hot water, which were formerly separate pans or boilers, are now supplied from one principal close boiler, similar to those used for steam-engines, by separate steam-pipes. When the economy of the steam is considered an object, the pipes for conveying the steam should be cased with wood, or otherwise covered with some bad conductor of heat, which will not be attracted by the heat of 212° .

The boiler, which supplies the steam, should be placed lower than any reservoir of water which it has to heat, as in that case the water, which may sometimes condense in the pipes, may run back into the boiler. This affords a little economy, by saving the degrees of heat between the hot water and the cold, with which the boiler is supplied. Another advantage is in the pipes not being liable to be choked by the condensing water not being allowed to get out of the way of the steam. For heating water in brew-houses, wash houses, dyeing-vats, &c. the steam-pipe comes directly into the water, the steam passing into the same making a loud noise, like the rapid cracking of a whip. For heating large baths and buildings, the steam is condensed in the pipes which pass round the baths or around the rooms, and the water should in this case run back into the boiler. The pipes, or other metallic vessels in which the steam is condensed for the purpose of warming rooms, should be coated with paint, the blacker the better. This is found to give out heat much more rapidly than the metallic surface, and in a still greater excess above a polished metallic surface.

When steam is employed for the purpose of heating

water, the supply for a given quantity of water will be easily calculated by the data already given.

Let L = the heat required to convert water into steam at 900° .

W = the weight of the water to be heated by steam.

T = its temperature.

t = the temperature to which it is required to be heated.

S = the weight of steam required.

b = the temperature of the steam.

Then $t = \frac{(L + b) S + W T}{S + W}$, and $S = \frac{t - T}{L + b - t} W$.

A simple rule for finding the quantity of steam required to raise a given weight to any given temperature arises out of this formula. Multiply the water to be warmed by the difference of temperature between the cold water and that to which it is to be raised for a dividend. Then to the temperature of the steam add 900, and from the sum take the required temperature of the water. This last remainder being made a divisor to the above dividend, the quotient will be the quantity of steam, in the same terms as the water.

What quantity of steam at 212° will raise 100 gallons of water at 60° up to 212° ? $\frac{(212 - 60) \times 100}{900} = \frac{152}{9} =$

17 gallons of water, formed into steam. This quantity of steam from a boiler containing about 27 cubic feet, with a fire applied to the best advantage, will be furnished in 2 hours and 16 minutes, supposing no heat to be lost by the heated mats being exposed. The coal consumed for this purpose will be about 23 or 24 lbs., depending on its quality.

The theorem above given will apply to any temperature above 212° , when the steam is under greater pressure than 30 inches of mercury. It will also appear from the table of the force of vapour, that any degree of heat short of endangering the vessels, may be given by steam under different degrees of pressure. Such means are at present employed for evaporating water from sugar, salt, and other fluids requiring a greater degree than 212 . It will be equally obvious, that an uniform heat may be kept up below 212° , by adjusting the steam-cock through which the medium to be heated is supplied. In giving heats above 212° , the vessels should be completely steam-tight, and very strong. The boiler should have a safety-valve, which should always be kept clean and free to act.

Steam is employed to great advantage for culinary purposes. It is made to communicate with vessels in the form of boilers, as a substitute for having fires under them, which is a great advantage, both in the economy of fuel, and in avoiding at the same time the nuisance of ashes and smoke.

The most convenient application of steam for culinary purposes is, when it directly acts upon the substance to be heated. This has been generally effected by placing the substance, whether meat or vegetables, in a vessel without water, and allowing the steam to enter and condense upon it. The most convenient apparatus of this kind we have yet heard of, consists of a cast-iron plate about 30 inches or three feet square, standing horizontally in a recess in the wall, like a table. Round the edge of this plate is a groove, about half an inch wide and two inches deep. Into this groove fits an inverted tin-vessel, like a dish-cover. This is capable of being elevated and depressed by a pulley and chain, having a coun-

terpoise, in order to expose the table at any time. The steam comes under the table and enters in the centre. The dishes to receive the heat are placed on any part within the groove, the steam being common to all. The water resulting from the condensation runs into the groove, and at a point short of the top runs off. The water which remains forms a complete water-lute, to prevent the escape of steam. The table being placed in a recess, like a common stone hearth, a small flue is placed over it to take away any steam that may escape when the cover is lifted up.

The great quantity of hot water required in a scullery should be perpetually kept up by a supply of steam. For this purpose a large cylindrical vessel of cast-iron should be elevated in a corner of the scullery, in order that water may be drawn from it by a cock. This vessel should be connected from the bottom with a cold-water cistern, the bottom of which is level with the top of the cylinder, by which the latter is kept constantly full. The hot-water cylinder is closed firmly at the top, and therefore, when the air is allowed to escape, the water rises to the top. If now a pipe be connected with the top, coming down to where it is to be drawn off, if any portion be drawn out here, as much will come in at the bottom of the cylinder from the reservoir above. So far we have described this cylinder without its steam-vessel. Within this cylinder, and about the middle, is a distinct vessel, nearly of the width of the cylinder; but having a free space round the inner vessel about an inch wide. The depth of the inner vessel must be about one-sixth that of the outer one. This inner vessel must have no connection with the outer one, and must be so water-tight, that although it is surrounded with the water of the outer one, none should get in. The inner vessel is on one side connected by a pipe with a steam-boiler, having another pipe to allow the condensed water to run off, which may be preserved as distilled water, and is valuable for many purposes. The heat arising from the condensation is communicated to the water in the outer vessel, the hottest being at the top, where the mouth of the exit-pipe is placed. When, therefore, a portion of hot water is drawn from the cock, the pipe of which comes from the top of the vessel immediately under the cover, an equal quantity comes in at the bottom from the reservoir. This useful apparatus is the invention of an ingenious economist of Derby, and is at present in use in his kitchen.

When steam is properly applied to the warming of baths, the economy is so great, that if it were known, these exquisite luxuries would soon become more fashionable. The steam is condensed in pipes about two or three inches in diameter, which are placed round the bottom of the bath. These pipes are concealed in a recess, which is afterwards covered by thin stone plinths, perforated with holes to allow the water to circulate.

We shall point out the economy of these baths, by giving some facts of a bath in common use. Its size is about 10 feet square, and its depth such as to contain about 520 cubic feet. The steam at 212° , to first raise it from 32° to 96° , will be found by the above theorem to be as much as will condense it into 33 cubic feet of water. This will be produced by 380lbs. of coal, including that required to raise the 33 cubic feet of water from 32° to 212° , which is always about $\frac{1}{4}$ th of what will afterwards make it into steam.

Supposing the bath to have double doors, and a small skylight instead of common windows, it will be found, when the outer air is 45° , that the bath will not cool more than 4° in 24 hours. To restore this every day, will require only $\frac{1}{16}$ th of what was required to raise it from 32° . This

will be about 23.5lbs. Supposing the whole of the water to be changed by a regular inlet and outlet every 14 days, then the weekly supply of coal for such a bath will be about 350lbs.

It is suggested by Dr. Darwin, that the art of boiling vegetables of all kinds in steam instead of water, might probably be managed to advantage, as a greater degree of heat might be thus given them, by contriving to increase the heat of the steam after it has left the water; and thus the vegetable mucilage in roots and seeds, as in potatoes and flour-puddings, as well as in their leaves, stems, and flower-cups, might be rendered probably more nutritive, and perhaps more palatable; but that many of the leaves of vegetables, as the fumits of cabbage-sprouts, lose their green colour by being boiled in steam, and look like blanched vegetables. This etiolation of some vegetables by steam is probably owing to its dissolving their colouring matter, which may then become decomposed, and may render them less agreeable to those who choose by the eye rather than the palate; which green colour is, however, heightened by boiling them in some hard waters which contain dissolved lime or sea-salt, or by a slight admixture of common salt with soft water; an effect which is owing to the evaporation of a part of the marine acid, and to the remaining alkali which was the basis of it, when applied to blueish vegetables converting them into green, as in the common experiment of adding salt of tartar to syrup of violets, or according to the custom of some cooks who add a little pot-ash, or fixed vegetable alkali, to the water in which young peas are boiled, to make them green, and afterwards a very little sugar to sweeten them. And the same effect of making vegetables green, when boiled in another kind of hard water, is probably produced by the lime which abounds in them, and which, like the vegetable alkali, when the aerial acid which was united with it evaporates, is said to convert blueish vegetable colours into green ones.

Steam has likewise lately been applied in gardening to the purpose of forcing plants of different kinds in the winter season, in order to have their produce at an early period, as to the cucumber, and some other vegetables of a somewhat similar nature; but the exact manner of its application in this intention, so far as we know, has not yet been communicated to the public; it is, however, by some mode of flues, pipes, and other contrivances for conveying and containing it, so as that its heat may be uninterruptedly, equally, and regularly afforded to the roots of the plants which it is designed to push forward into the fruiting state. It is said to have been used in some instances in different parts of Lancashire with great success. But how far the expence and advantage of such a method may admit of and encourage its being introduced into general practice, have not, probably, yet been well or fully ascertained. If it should be found capable of perfectly succeeding in this use, on more full and correct experience, it will, however, constitute not only a neat and clean, but an elegant mode of forcing plants into fruit at early seasons.

It has been found that subterranean steams often affect the surface of the earth in a particular manner, and promote or retard vegetation more than almost any thing else.

STEAM-Engine, or Fire-Engine, a machine very generally employed in this country as a first mover of other engines and machines, its mechanical force or moving power being obtained from the expansion or contraction of the steam of boiling water. Until of late years this machine was called the fire-engine, because it is in reality actuated by the fire which causes the water to boil.

Steam Engine

The steam-engine is an invention highly creditable to human genius and industry, and is amongst the most valuable applications of philosophical principles to the arts of life. The invention of a ship, with all her accessories, and the degree of knowledge requisite to conduct her through a distant voyage, are more striking instances of the power of the mind of man, and of his enterprising disposition; whether we consider the number of sciences which must be applied to practice in the construction and management of a vessel; or the advantages which mankind have derived from such an invention, and the improvements which it has occasioned in the state of civilization, by uniting, in a great degree, all the inhabitants of the globe in one society, who mutually supply each other's wants, and who all contribute their share to the general stock of knowledge.

The steam-engine follows next to the ship in the scale of inventions; but in an English Cyclopædia it will take the lead, from the circumstance of its being wholly invented, and brought into general use, by our own countrymen, within the space of a single century; and also as having been the principal means of effecting those great improvements which have taken place in all our national manufactories within the last thirty years; and the increase of our commerce which has ensued.

The art of navigation is the result of the combined ingenuity and experience of all nations, from the earliest period of history to the present time; and the successive and almost imperceptible improvements by which it arrived at its present state of perfection, have many of them been the productions of accident, and for which we do not exactly know to whom we are indebted. But the steam-engine is the invention of a few individuals, all of them Englishmen, and brought into general use within a century. In the first beginning it was the result of reflection, and the production of a very ingenious mind; and every alteration in its construction and principle was also the result of philosophical enquiry.

General Principle of the Steam-Engine.—The force of the steam-engine is derived from the property of water to expand itself, in an amazing degree, when heated above the temperature at which it becomes changed into steam, or vapour, which being an exceedingly elastic fluid, it can be retained within the close vessel or boiler to which the heat is applied, even when it has an expansive force sufficient to make it fill, if left at liberty, 20 or 30 times the space in which it is confined. In this state the steam will exert a proportionate force or pressure to burst open the sides of the vessel in which it is retained; which force may be applied either to expel or raise up water from any vessel into which the confined steam is admitted, or to give motion to a moveable piston, which is so accurately fitted to the interior capacity of such vessel, as not to permit the escape of the steam between them.

Another source of the power of the steam-engine is the facility with which steam of a great expansive force can be cooled by the application of cold water, and condensed into the small quantity of water from which it was originally produced. A partial vacuum can thus be made, in a very large vessel, in an instant, and even in the same vessel, which was, a moment before, filled with confined steam, exerting a great force to escape. The pressure of the atmosphere which tends to fill up this vacuum, can be made to produce the ascent of water into the vessel to any height less than twenty-four or twenty-five feet. Or the pressure of the atmosphere may be made to give motion to a piston, by admitting the atmospheric air to press upon one side of

the piston, whilst there is a vacuous space formed by the condensation of the steam which filled the cylinder on the other.

Notwithstanding the great variety of different constructions of the steam-engine, they all derive their force from one of these two principles, or from the combination of the two: but before entering upon any description of the manner in which these forces are applied, it is necessary to have clear ideas of the nature of steam, and of the law by which it expands by heat, in order to form a precise judgment of what passes in the interior part of a steam-engine when it is at work. In the common acceptance of the word steam, it is that hot white vapour which we see every day rising in a cloud from a tea-kettle or boiling-pot; but this is not exactly the state of the steam employed in an engine; it is there perfectly transparent, and is more or less hot than boiling water, according as it is retained under a lesser or greater degree of compression. The ordinary pressure of the atmosphere, bearing upon the surface of water, will retain it in a state of fluidity, until it is heated to what is generally called the boiling point, and is marked 212° in Fahrenheit's thermometer. If the heat is increased above that degree, and if the water is unconfined, except by the pressure of the atmosphere, the water immediately assumes the aeriform state, and flies off in elastic vapour, which we call steam; but if the same water is relieved from the pressure of the atmosphere by enclosing it in a close vessel, and exhausting the air from it, a certain portion of steam or vapour will rise from the same at any temperature, even when it is as low as freezing; and if this vapour is conveyed off from the vessel as fast as it rises, the water, although cold, will boil, and such vapour will rise as fast as the boiling kettle does in the open air. If the vapour is retained in the vessel, it will only accumulate, until it has acquired a certain degree of elastic force to press upon the surface of the water, which will then cease to yield any more vapour, until the heat is farther increased, or that the vapour is drawn off to relieve the water from the pressure which confined and retained it in its fluid state. On the other hand, water which is retained in a close vessel, under a greater degree of pressure than that occasioned by the pressure of the atmosphere, will not boil or rise in vapour, until it becomes heated to a higher temperature than 212°. It is even probable, that water might be compressed to that degree, that it would not boil until heated red-hot; but this would require such an enormous strength in the vessel which should contain the steam, that it is far beyond the practicability of an experiment.

In this manner the reader is to bear in mind, that vapour or steam, when confined in close vessels, is always more or less elastic, in proportion to the degree of heat which is applied to it; or, in other words, that the temperature of the steam is an exact index of the elastic or expansive force with which it presses upon the surface of the water, and against the interior surface of the vessel which contains it.

The following tables shew the law by which the expansive force increases with the increase of the temperature. They were made from the experiments of Mr. John Dalton, which he published at length in the "Memoirs of the Literary and Philosophical Society of Manchester," and experiments have been also made in France by M. Betancourt, which do not differ from this table so much as to affect the results in any great degree, when applied to practice, in calculating the force of steam-engines. These experiments were made by enclosing water in a close vessel, from which the air was carefully exhausted, so as to make a vacuum. A thermometer was applied, so as to indicate

the temperature of the interior of the vessel; also there was a communication made from the vessel to the lower part of a siphon barometer tube, that is, an inverted glass siphon filled with mercury, from one leg of which the pressure of the atmosphere was excluded, and the other leg communicated with the interior of the vessel. In this way, when there was a vacuum in the vessel, the surface of the mercury in the two legs of the siphon would stand at the same level, because it would not be pressed upon at all on either side; but when any vapour was raised in the vessel, it would press upon the interior surface thereof, and also upon the surface of the mercury in one of the legs of the inverted siphon; and as the surface of the mercury in the other leg would not be pressed upon at all, the mercury would mount in one leg and descend in the other, and the difference of the level between the two being measured, would express the elastic force of the vapour, which was found to increase with the increase of the heat, according to the second column of the table. For the convenience of estimating the force of the vapour, we have added the third and fourth columns to Mr. Dalton's table. The third, to express the pressure

by the altitude of a column of water, instead of mercury; and the fourth column to shew the pressure upon each square inch of the surface upon which the vapour acts, in pounds avoirdupois and decimals. The table also shews, in the three last columns, the difference of pressure between the vapour and atmospheric air in three different terms, viz. in the column of mercury, column of water, and in pounds on the square inch.

In the first table, which is for every 10° of temperature up to 212° , or the heat of boiling water when in the open air, the three last columns shew how high the pressure of the atmospheric air, when the barometer is at 30 inches, will force up mercury or water in a tube, which at the upper end communicates with the vessel containing the vapour, and the lower end is immersed in the mercury or water. And in the second table, which is for the degrees of heat above 212° , the same columns shew to what height the force of the vapour will cause mercury or water to mount up in a tube, which at the lower end communicates with the vessel containing the steam, and the upper end is open to the atmospheric air.

TABLE of the expansive Force of the Vapour of Water, or Steam, when enclosed in a close Vessel, and relieved from the Pressure of the Atmosphere; taken at every 10° of Temperature, from the Congelation of Mercury, or 40° below the Zero of Fahrenheit, up to 212° , or boiling.

Temperature in Degrees of Fahrenheit's Thermometer.	Pressure of the Vapour, or the Force which it will exert to enter into a vacuum Space.			Pressure of the Atmosphere, or the Force which it will exert to enter into a Space filled with the Vapour. Barometer supposed to be at 30 inches.		
	Column of Mercury.	Column of Water.	Pressure per square Inch.	Column of Mercury.	Column of Water.	Pressure per square Inch.
	Inches.	Ft. In.	Lbs. Oz.	Inches.	Ft. In.	Lbs. Oz.
- 40 } below zero.	.01	0 .17	0 .1	29.987	33 10.63	14 10.5
- 30 }	.02	0 .27	0 .15	29.98	33 10.53	14 10.45
- 20 }	.03	0 .4	0 .23	29.97	33 10.4	14 10.37
- 10 }	.043	0 .58	0 .33	29.957	33 10.22	14 10.27
0	.064	0 .87	0 .5	29.936	33 9.93	14 10.1
10	.09	0 1.22	0 .7	29.91	33 9.58	14 9.9
20	.129	0 1.75	0 1.	29.871	33 9.0	14 9.6
30	.186	0 2.5	0 1.44	29.814	33 8.3	14 9.16
32 (freezing.)	.2	0 2.7	0 1.56	29.8	33 8.1	14 8.04
40	.263	0 3.5	0 2.	29.737	33 7.3	14 8.6
50	.375	0 5.1	0 2.9	29.625	33 5.7	14 7.70
60	.524	0 7.1	0 4.1	29.476	33 3.7	14 6.5
70	.721	0 9.8	0 5.6	29.279	33 1.	14 5.
80	1.	1 1.56	0 7.83	29.	32 9.24	14 2.77
90	1.36	1 6.5	0 10.4	28.64	32 3.25	14 0.2
100	1.86	2 1.25	0 14.4	28.14	31 9.5	13 12.2
110	2.53	2 10.25	1 3.6	28.47	31 0.5	13 7.
120	3.33	3 9.	1 10.	27.67	30 1.	13 0.6
130	4.34	4 10.75	2 1.5	25.66	29 0.	12 9.1
140	5.74	6 6.	2 13.	24.26	27 4.	11 13.6
150	7.42	8 4.5	3 9.8	22.58	25 6.25	11 0.8
160	9.46	10 8.	4 9.9	20.54	23 2.	10 0.7
170	12.13	13 8.5	5 14.7	17.87	20 2.25	8 11.9
180	15.15	17 1.5	7 6.4	14.85	16 9.25	7 4.2
190	19.00	21 3.5	9 3.3	11.	12 7.25	5 7.3
200	23.64	26 8.5	11 8.9	6.36	7 2.25	3 1.7
210	28.84	32 7.	14 1.9	1.16	1 3.	0 8.7
212 (boiling.)	30.	33 10.75	14 10.6	the vapour and the atmosphere equal.		

TABLE of the expansive Force of Steam, when enclosed in a close Vessel, taken at every 5° of Temperature, from 212° of Fahrenheit, or boiling, up to 325°.

Temperature in Degrees of Fahrenheit's Thermometer.	Pressure of the Steam, or the Force which it will exert to enter into a vacuum Space.			Pressure of the Steam against the Atmosphere, when the Barometer is at 30 Inches, or the Force which it will exert to escape from the close Vessel into the open Air.		
	Column of Mercury.	Column of Water.	Pressure per square Inch.	Column of Mercury.	Column of Water.	Pressure per square Inch.
	Inches.	Ft. • In.	Lbs. Oz.	Inches.	Ft. In.	Lbs. Oz.
212 (boiling.)	30.	33 10.75	14 10.6	the steam equal to the atmosphere.		
215	31.83	35 11	15 9	1.83	2 0	0 15
220	34.99	39 6	17 1	4.99	5 7	2 7
225	38.20	43 2	18 10	8.20	9 4	4 0
230	41.75	47 2	20 7	11.75	13 4	5 13
235	45.58	51 6	22 5	15.58	17 8	7 11
240	49.67	56 1	24 4	19.67	22 3	9 10
245	53.88	60 10	26 4	23.88	27 0	11 10
250	58.21	65 9	28 8	28.21	31 11	13 14
255	62.85	71 0	30 12	32.85	37 2	16 2
260	67.73	76 6	33 2	37.73	42 8	18 8
265	72.76	82 2	35 9	42.76	48 4	20 15
270	77.85	87 11	38 1	47.85	54 1	23 7
275	83.13	93 11	40 11	53.13	60 1	26 1
280	88.75	100 3	43 7	58.75	66 5	28 13
285	94.35	106 7	46 3	64.35	72 9	31 9
290	100.12	113 1	49 0	70.12	79 3	34 6
295	105.97	119 8	51 4	75.97	85 10	36 10
300	111.81	126 4	54 12	81.81	92 6	40 2
305	117.68	132 11	57 9	87.68	99 1	42 15
310	123.53	139 6	60 8	93.53	105 8	45 14
315	129.29	146 1	64 0	99.29	112 3	49 6
320	135.	152 6	66 1	105.00	116 5	51 7
325	140.70	158 11	68 14	110.70	125 1	54 4

History of Invention of the Steam-Engine.—The great elastic force of steam has been long known in the instrument called the *aeolipile* (see that article); and its property of condensation was also experienced in the use of the same instrument: the manner commonly practised for filling the ball with water being to plunge it into cold water, when heated and filled with steam; by which means the steam is condensed, and forms a vacuum sufficient to draw the water into the ball, although the orifice is so small that water could not be introduced by any other means. At the same time, the true principles of its action were so little understood, that the steam which issued from it, when placed on the fire, was supposed to be air produced by the decomposition of the water; and nearly all the old philosophers, who have described this instrument, proposed to employ it for blowing furnaces. The first idea of employing this force of steam to produce motion was by Brancas, a philosopher of Rome, who contrived a great number of different kinds of mills to be worked by the steam coming from a large aeolipile, and blowing against the floats or vanes of a wheel. We are obliged to this author for a number of other ingenious inventions, which he dedicated to M. Canci, governor of Loretto, in 1628, and published his work (*Le Machine*) at Rome the year following. The representation of his fire-machine is given in the twenty-fifth plate; but the force which he could have thus obtained from steam would have been found altogether inconsiderable, if he had ever put it in practice.

The first real steam-engine was invented by the marquis of Worcester; but it was only for raising water, and that by the expansive force of steam alone. The next engine was by captain Savery, and operated, both by the expansive force and the pressure of the atmosphere, to fill up the vacuum which was produced by the condensation of the same steam, after it had ceased to operate by its expansion. These actions were employed alternately to raise water. The third inventor, Newcomen, abandoned the force of expansion, and only employed the condensation of the steam to obtain a vacuum, and cause the pressure of the atmosphere to act, unbalanced upon a piston, fitted into a cylinder; and as the force was thus exerted upon a moveable piston, his machine is capable of being applied to give motion to pumps or other machines, whereas his predecessors were obliged to confine themselves to the raising of water. Soon after this invention, engines were proposed with pistons to be actuated by the expansive force of the steam only, without the vacuum. Lastly, Mr. James Watt invented the engines now in general use, which are actuated both by the pressure of steam, and the vacuum acting at the same time upon the opposite surface of the piston.

We owe too much to these inventors, as well as many others, to pass over their discoveries with such slight notice; and shall, therefore, give a detailed history of the progress of this valuable invention, drawn from the best authorities we have been able to obtain.

The Marquis of Worcester's Steam-Engine.—The earliest

description which we have of a machine for raising water by fire, employed in raising steam from boiling water, is from the marquis of Worcester, who, in the reign of king Charles II., and in the year 1663, published a small pamphlet, entitled "A Century of the Names and Scantlings of the Marquis of Worcester's Inventions," written in 1655.

This little work, it appears, was addressed to the king and parliament, and published with a view to obtain an encouragement from the public for the prosecution of 100 projects, which it details. No. 68. of this Century contains as follows:—"68. An admirable and most forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be as the philosopher calleth it *intrâ spheram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessel be strong enough: for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole; and making a constant fire under it, within twenty-four hours it burst, and made a great crack; so that having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream forty feet high: one vessel of water, rarefied by fire, driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and re-fill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

This passage certainly contains a description of an engine for raising water by the repellent power of steam; and from his expression, of one vessel of water, converted into steam, forcing up forty vessels of cold water to the height of forty feet, it is very probable that he had actually tried the experiment by a working model.

The marquis concluded his Century of Inventions by a promise to leave to posterity a book, wherein under each head the means of putting his several inventions in execution were to be described, with the assistance of plates; but as this work never appeared, we can only judge of his abilities by this specimen. He appears to have been a person of much knowledge and ingenuity; but his obscure and enigmatical account of these inventions seems not so much intended to instruct the public as to raise wonder; and his encomiums on their utility and importance are, to a great degree, extravagant, resembling more the puff of an advertising tradesman, than the patriotic communications of a gentleman. The marquis of Worcester was indeed a projector, and very importunate and mysterious withal in his applications for public encouragement.

It does not appear that he met with any public encouragement to his propositions; and though, at first sight, it seems surprising that an invention, by which the steam of boiling water is stated to be capable of producing a power equal to that of gunpowder, should be neglected for almost forty years; yet if we consider that the greater part of this Century of Inventions consists of things highly in the style of legerdemain, and some of them absolutely impossible, and contrary to all established rules of science, we need not so much wonder at the neglect which the whole experienced. For example, the 90th number of the Century is as follows: "How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pounds descending doth what nothing less than one hundred pounds can effect."

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It must be also further considered, that these projects were published at a time when true science was beginning to take place of empiricism.

The Century of Inventions appeared about three years after the establishment of the Royal Society, during the time of Mr. Boyle, Dr. Hooke, Dr. Wallis, sir Christopher Wren, sir Isaac Newton, and others equally skilled in calculations, as in the inventive parts of mechanics.

Under all these circumstances, it is not astonishing that the marquis's propositions in general should meet with a cool reception, or that this celebrated invention should be condemned to obscurity, amongst the other wonders with which it was accompanied.

We do not wish it to be understood, that all the marquis's propositions, except the fire-engine, are of the same nature as No. 99: on the contrary, several have been reinvented, and proved true, since the marquis's time; for example, short-hand telegraphs, floating baths, carriages from which the horses can be disengaged if unruly, combination locks, secret escutcheons for locks, candle-moulds, &c. It is also probable that others may be brought to perfection; yet the greater part is so much in the style of the wonderful, that it is to be wished that the marquis had published nothing but No. 63, which at once would have rendered his name immortal, and without any tarnish or alloy to the glory of so great an invention.

Captain Savery's Steam-Engine.—The next attempt upon record is that of captain Thomas Savery, a commissioner of the sick and wounded, who, in the year 1698, obtained a patent for a new invention for raising water, and occasioning motion to all sorts of mill-work, by the impellent force of fire. This patent bears date the 25th July, in the tenth year of the reign of William III., that is 1698. The patent states that the invention will be of great use for draining of mines, serving towns with water, and for working all sorts of mills.

In June 1699, he shewed a working model of his engine to the Royal Society, and in their Transactions for that year, viz. N° 253, vol. xxi. there is the following register.

"Mr. Savery, June 14th, 1699, entertained the Royal Society with shewing a small model of his engine for raising water by the help of fire, which he set to work before them: the experiment succeeded according to expectation, and to their satisfaction."

The above is accompanied with a copper-plate figure, with references by way of description, from whence it appears, that the engine then shewn by captain Savery was for raising water not only by the expansive force of steam, like the marquis of Worcester's, but also by the condensation of steam, the water being first raised by the pressure of the atmosphere to a given height from the well into the engine, and then forced out of the engine up the remaining height by the expansive force of steam, in the same manner as proposed by the marquis. This action was performed alternately in two receivers, so that while the vacuum formed in one was drawing up from the well, the pressure of the steam in the other was forcing up water into the reservoir; but both receivers being supplied by one suction-pipe and one forcing-pipe, the engine could be made to keep a continual stream, or so nearly so as to suffer very little interruption.

The inventor afterwards published an account of his engine in a small book, entitled "The Miner's Friend, or an Engine to raise Water by Fire described, and the Manner of fixing it in Mines, with an Account of the several Uses it is applicable unto, and an Answer to the Objections made against it," printed at London in 1702, by Thomas Savery, gentleman.

man. This little book was separately addressed to king William III., to whom the engine had been shewn at Hampton Court, to the Royal Society, and also to the Mine Adventurers of England, who were invited to adopt the invention.

This engine displays much ingenuity, and is almost as perfect in its contrivance as the same kind of engine has ever been made since that time: we have on that account copied the principal figure, and captain Savery's own description, as given by Dr. Harris, in his *Lexicon Technicum*. See *Plate I. Steam-Engine, fig. 1*.

Captain Savery's Description of his Fire-Engine.—"A denotes two furnaces, whose fire-places are marked B 1 and B 2, and their common funnel or chimney C.

"In these two furnaces are placed two vessels of copper, which I call boilers, the one a larger, as L, the other a smaller, as D.

"These boilers have each a gauge-pipe, as G and N, of which G goes within eight inches of the bottom of the small boiler, but N reaches only half way down into the great boiler.

"By these pipes, before the engine can work, you must fill the small boiler quite full, and the great boiler two-thirds full of water. Then light the fire under the large boiler at B 1, and make the water therein boil, by which means the steam of it being quite confined must needs be wonderfully compressed, and therefore will, on the opening of a way for it to issue out (which is done by pushing the handle Z of the regulator from you), rush with a great force through the steam-pipe O 1, into the receiver P 1, driving all the air before it, and forcing it up into the force pipe through the clack R 1, as you will perceive by the noise and rattling of the clack; and when all the air is thus driven out, the receiver P 1 will be very much heated by the steam. When you find it is thoroughly emptied, and is grown very hot, as you may both see and feel, then pull the handle Z of the regulator towards you, by which means you will stop the steam-pipe O 1, so that no more steam can yet come into the receiver P 1, but you will open a way for it to pass into O 2, and by that means fill the other receiver P 2 with the steam, as the other was before.

"While this is doing, let some cold water be poured on the first-mentioned receiver P 1, by which means the steam in it being cooled and condensed, and contracted into a very little room, and consequently pressing but very little (if at all) on the valve or cock R 1, at the bottom of the receiver P 1, there is nothing there to counterbalance the pressure of the atmosphere on the surface of the water, in the lower part of the sucking-pipe T, wherefore it will be pressed up, and ascend into, and fill the receiver P 1, driving up before it, as it rises, the clack or valve R 3, which afterwards falling down again and shutting close, hinders the descent of the water that way.

"Then (the receiver P 2 being in the mean time emptied of its air) push the handle of the regulator from you, and the force of the steam coming from the boiler, will act upon the surface of the water contained in the receiver P 1, where it forces or presses hard upon it, and still increases its elasticity or spring until it exceeds the weight of the column of water in the receiver and pipe S, which then it will necessarily drive up through the passage Q R, 1 Q Q, into the force-pipe S, and at last discharge it out at the top, as is represented in the figure.

"After the same manner, though alternately, is the receiver P 2 filled and emptied of water, and by this means a regular stream is kept continually running out at the top of the force-pipe S, and so the water is raised very easily from

the bottom of the mine, &c. to the place where it is designed to be discharged.

"Only I should add, that after the engine begins to work, and the water is risen into and hath filled the force-pipe S, then it fills also the little cistern X, and by that means feeds the pipe Y Y, which I call the condensing pipe, and which can be turned sideways over either of the receivers, and will then be open: by this cold water is conveyed down from the force-pipe to fall upon the outsidings of the receivers when thoroughly heated by the steam, in order to condense the steam within, and make them suck (as it is usually called) the water out of the well up into the receiver.

"Also a little above the cistern goes the pipe E, to convey water from the force-pipe into the lesser boiler D, for the purpose of replenishing the great boiler L, when the water in it begins to be almost consumed. Now when there is need of doing this, turn the cock E, so that there can be no communication between the force-pipe S and the lesser boiler D; and putting in a little fire under the small boiler B 2, the water will there grow presently hot; and when it boils, its own steam, which hath no vent out, pressing on its surface, will force the water up the pipe H, through K, into the great boiler L, and so long will it run till the surface of the water in the boiler D gets to be as low as the bottom of the pipe H, and then the steam and water will run together, and by its noise, and rattling of the clack I, will give him that works the engine sufficient assurance that the small boiler hath emptied and discharged itself into the greater one L, and carried in as much water as is then necessary; after which, by turning the cock E again, you may let new cold water out of S into the lesser boiler D, as before, and thus there will be a constant motion and a continual supply of the engine, without fear of decay or disorder.

"Also, to know when the great boiler wants replenishing or not, you need only turn the gauge-cock N, and if water come out there is no need to replenish it, but if steam only come, you may conclude there is want of water; and the like will the cock G do in reference to the lesser boiler D, shewing when it is necessary to supply that with fresh water from S; so that in working the engine there is very little skill or labour required: it is only to be injured by either a stupid or wilful neglect."

The engine above described does not differ essentially from that represented in the print in the *Philosophical Transactions*, but it is more neatly put into form, and improved in some of the minor particulars. For instance, the original engine had only one boiler, and there was no means of supplying it with water, to replace the waste occasioned by the evaporation of the steam, without stopping the action of the engine whenever the boiler was emptied to such a degree, as to risk the burning of the vessel. And after the boiler was replenished, the engine could not begin to work again, until that water which was introduced cold was made to boil.

The engine which we have just described from the *Miner's Friend* has a subsidiary boiler, in which a quantity of water is reduced to a boiling heat in readiness for supplying the great boiler, and the power of the steam raised in the subsidiary boiler is employed to force the water contained in it into the other, or great boiler, which actuates the engine: by this means the transposition of the feeding water is not only instantly performed, but being at a boiling heat, it is immediately ready to produce steam for carrying on the work. There is also another grand improvement in the construction of this engine. His first engine was worked by four separate cocks, which the operator was obliged to turn

turn separately at every change of stroke; and if he turned them wrong, he was not only liable to damage the engine, but he prevented its effect, and lost a part of the operation; whereas in this second engine the communications are made by the double sliding-valve, or regulator, as it has since been called. 'This is a brass plate, shaped like a fan, and moving on a centre within the boiler, so as to slide horizontally in contact with the under surface of the cover of the boiler, to which it is accurately fitted by grinding, and thus at pleasure opens or shuts the orifices or entries to the steam-pipes of the two receivers alternately. This regulator acts with less friction than that of a cock of equal bore; and by the motion of a single handle backwards, at once opens the proper steam-pipe from one receiver, and closes that which belongs to the other receiver.

The contrivance of the regulator has since proved of more consequence, as having been universally adopted in the cylinder engines.

Captain Savery, in the *Miner's Friend*, above referred to, in addition to the description of his engine, enumerates the following uses to which it may be applied, and which he describes rather fully, as follows; *viz.* 1st, to raise water for turning all sorts of mills; 2dly, supplying palaces, noblemen's and gentlemen's houses with water, and giving the means of extinguishing fires therein, by the water so raised; 3dly, the supplying cities and towns with water; 4thly, draining fens and marshes; 5thly, for ships; 6thly, for draining mines of water; and 7thly, for preventing damps in the said mines.

Dr. Harris, in his account of the fire-engine, speaks of captain Savery as one that he was acquainted with, and as a person of great merit and ingenuity. He first mentions another machine of Savery's, for rowing a ship in a calm by paddle-wheels placed at the vessel's side, of which the captain published an account in 1698; and it is worthy of remark, that the same kind of wheels, when actuated by improved steam engines, is the only method, amongst an infinite number of others, which at present has been found to answer for rowing vessels. Dr. Harris, in proceeding to the fire-engine, says, "The other engine is for raising water by the force of fire, in which he has shewn as great ingenuity, depth of thought, and true mechanic skill, as ever discovered itself in any design of this nature." Notwithstanding this, Dr. Defaguliers has endeavoured to take away all the merit of the invention of the fire-engine from captain Savery, as if he had merely copied it from the marquis of Worcester.

The account given by Dr. Defaguliers has been so frequently copied by different writers, that it is generally considered as correct; and we therefore think it a piece of justice to the memory of captain Savery, to set his pretensions in a clearer light than has been generally done. The doctor says, "Captain Savery having read the marquis of Worcester's book, was the first who put in practice the raising water by fire, which he proposed for the draining of mines. His engine is described in Harris's *Lexicon*, (see the word *ENGINE*;) which, being compared with the marquis of Worcester's description, will easily appear to have been taken from him, though captain Savery denied it; and the better to conceal the matter, bought up all the marquis of Worcester's books that he could purchase in Paternoster-Row, and elsewhere, and burned them in the presence of the gentleman, his friend, who told me this. He said that he found out the power of steam by chance, and invented the following story to make people believe it; *viz.* that, having drank a flask of Florence at a tavern, and thrown the empty flask upon the fire, he called for a basin

of water to wash his hands, and perceiving that the little wine left in the flask had filled up the flask with steam, he took the flask by the neck, and plunged the neck of it under the surface of the water in the basin, and the water of the basin was immediately driven up into the flask by the pressure of the air. Now he never made such an experiment then nor designedly afterwards, which I thus prove. —

"I made the experiment purposely, with about half a glass of wine in a flask, which I laid upon the fire till it boiled into steam; then putting on a thick glove to prevent the neck of the flask from burning me, I plunged the mouth of the flask under the water that filled a basin, but the pressure of the atmosphere was so strong, that it beat the flask out of my hand with violence, and threw it up to the ceiling. As this must also have happened to captain Savery, if ever he had made the experiment, he would not have failed to have told such a remarkable incident, which would have embellished his story."

This conclusion of the doctor's is altogether unphilosophical, and does not at all invalidate captain Savery's account. We know that the marquis of Worcester gave no hint concerning the contractibility or sudden condensation of steam, upon which all the merit of the modern engine depends. The marquis of Worcester's engine was actuated wholly by the elastic power of steam, which he either found out, or proved by the bursting of a cannon, in part filled with water; but he gave not the least hint that steam so expanded is capable of being again so far contracted in an instant, as to leave the space it occupied in a vessel in a great measure a vacuum. This grand discovery was reserved to captain Savery, and his account of its accidental origin is not at all improbable. The captain tells us in the *Miner's Friend*, that he did not bring his design to bear, until after a great number of fatiguing inquiries: and he actually erected several machines before he obtained his patent in July 1698. Many objections were made against the grant of that patent being passed; but in the hearing of these objections, the discovery of the marquis of Worcester's prior claim was not mentioned; and, indeed, it is certain that the account given in the *Century of Inventions* could not instruct a person who was not sufficiently acquainted with the properties of steam to be able to invent the machine himself.

Defaguliers seems to have been too hasty in concluding that the captain had never made such an experiment as that of the wine-flask, because, in the single instance in which he tried it himself, he found the effect of the condensation took place in a much higher degree than reported by the captain. It is not difficult to conceive that a very small difference in the heat of the steam which filled the flask, and other circumstances, might create the whole of the difference in the result. And, on the whole, there is no reason to hesitate in believing that the captain actually took his hint of the condensation of steam from such an accident, and being of a very mechanical genius, he would naturally turn his thoughts towards the consideration of such a power; and the most obvious application of it would be to a machine on a construction similar to that described by the marquis. Or, if he really had been acquainted with, and considered the marquis's engine, he would easily see that the new principle of condensation might, with great advantage, be combined with the former, and thereby produce an effect more powerful than either of them could do alone. The only thing in the doctor's account which cannot now be disproved is, that captain Savery destroyed the marquis of Worcester's books. Even if this is true, it may be accounted for; the captain must, first or last, have become acquainted with what had been before made public by the marquis of Wor-

celter; and after having in his books spoken of *his invention*, and his new power or cause of motion, and finding the marquis's inventions to be but little known, he might be tempted, in order to secure the whole credit and expected advantage to himself, to buy up the marquis's books and burn them. But the grounds for this assertion are very slight, and will never prevent the conclusion, that the great principle of obtaining force from the pressure of the atmosphere, by the condensation of the steam of boiling water, was a discovery for which we are indebted to captain Savery, who had also the merit of first reducing it to practice in a most complete manner, in combination with the prior discovery of the marquis.

M. Amontons' Fire-Wheel.—The French writers who have treated of the steam-engine, seldom fail to mention Papin and M. Amontons as the first inventors of the method of raising water by steam, and speak of Savery as a person who put their ideas in execution, and brought them to perfection: we think it right on this account to state what was done by M. Amontons and Papin, although the attempts of the latter to employ the force of steam are not entitled to any notice, either from their originality, or from their real merit. It is probable, that the news of the patent granted to Savery in 1698, for raising water, and occasioning motion to mill-work by the impelling force of fire, excited the attention of the French academicians, before the means by which it was to be accomplished were made public, so as to be known abroad, and that they were thus induced to attempt the same thing; for in June 1699, which is the same month that captain Savery shewed his machine at work before the Royal Society, M. Amontons delivered a memoir to the Royal Academy of Sciences at Paris, entitled "A commodious Way of substituting the Action of Fire instead of Men and Horses to move Machines."

This may be regarded as the first attempt to produce a circular motion by the means of fire, otherwise than by the æolipile, or the fly of a smoke-jack: but as the motion of M. Amontons' wheel was to be produced by the alternate dilatation and contraction of air, and not of the steam of boiling water, it is nothing in common with Savery's machine, except that the first cause of motion is that of fire.

M. Amontons' fire-wheel, as he called it, consists of a number of close buckets, or chambers, placed in the circumference of a hollow wheel, and communicating with each other by valves opening in one direction; and a sufficient quantity of water is put into these buckets to fill about one half of the number: another circle of similar buckets, but of larger dimensions, are placed on the outside of the circle of the former buckets; these large buckets contain air, and each one has a pipe conducted from it to one of the water-buckets which are nearer to the centre: a part of the circumference of the wheel, which is about the level of the centre, is exposed to the fire of a furnace, so that each air-bucket that passes will be heated; and also the lower part of the wheel is immersed in a cistern of cold water, so as to cool the same bucket again. The action of the machine may easily be understood. The air contained in the large bucket which is opposite the fire becomes heated and expanded, and by the pipe of communication it enters into that water-bucket which is at the lower side of the wheel, and pressing upon the surface of the water therein, causes it to mount up through the other chambers, in the direction in which the valves open from one chamber to the next; the water, being thus accumulated in the chambers at one side of the wheel, will give it a preponderating power to turn round upon its axis. This motion brings another air-bucket opposite to the fire, and the air therein expands in its turn, and again

elevates the water in the interior chambers as much as it had descended by the motion of the wheel; a continual succession is thus kept up, and the air-buckets which have passed the fire descend into the cold water, and the air is thereby cooled and reduced to its former bulk. By the communication with the water-buckets, the pressure of the expanded air is removed from within them, and puts them in a situation to repeat their action.

This machine is ingenious, and if a better application of fire, by rarefying water into steam, had not been discovered, it is possible that the invention of M. Amontons might have been further prosecuted. From his computations it would appear, that the machine he proposed would act with a considerable power; but as he exhibited no working model, or actual trial, it was never proved that the machine, if put into practice, would be capable of producing any thing near the effect promised by his calculations. Leupold, in his "*Theatrum Hydraulicarum*," 1724, proposed an improved form of this fire-wheel; and steam-engines have been since made with mercury, or fluid metal, contained within a hollow wheel, which is to be always kept on one side with the mercury by the force of the steam: they have not been found to equal other modes of applying the force of steam. Such of our readers as are curious to know more of the construction of M. Amontons' machine, can consult the original memoir; and they will also find a full account of it, with a figure, in Martin and Chambers's *Abridgment of the Philosophical History and Memoirs of the Royal Academy of Sciences at Paris*, vol. i.

Papin's Pretensions to the Invention of the Steam-Engine.—M. Papin, to whom the French attribute the invention of the steam-engine, was a doctor of physic, and professor of mathematics at Marburg, in Germany, and in 1680 he was elected a fellow of the Royal Society of London. In the following year, and whilst in London, he invented and published a method of dissolving bones, and other animal solids, in water, by confining them in close vessels, which he called digesters, and which he made sufficiently strong to retain the steam and prevent all evaporation, so as to acquire a great degree of heat. About the same time Dr. Hooke, the most inquisitive experimental philosopher of that inquisitive age, observed that water could not be made to acquire above a certain temperature in the open air, and that as soon as it begins to boil, its temperature remains fixed, and an increase of heat only produces a more violent ebullition, and a more rapid waste. Papin's experiments with his digester rendered the elastic power of steam very familiar to him, and when he left England, and settled as professor of mathematics at Marburg, he made many attempts to employ this force in mechanics, and even for raising water.

By his own account, it appears that he had made some experiments with this view in 1698, by order of Charles, landgrave of Hesse, but without effecting any thing. This is all the reason the French have to consider him as the first inventor of the steam-engine. Nine years after Savery's patent he published an account of his invention, in a tract, entitled "*Ars nova ad aquam ignis adminiculo efficacissime elevandum*"—"A New Method of raising Water by the Force of Fire," printed at Cassel, 1707. This machine, which is described in Belidor's "*Architecture Hydraulique*," vol. ii. does not essentially differ from that of the marquis of Worcester, but is far less perfect than Savery's: it works wholly by the repellent power of steam: the only advantage is, that the receiver being made cylindrical, the steam is separated from the cold water by a floating piston, and that the water is made to flow in some degree constantly, by being thrown into a large air-vessel. In this publication, Papin

admits that he had seen a draft of Savery's engine, but says, that in the year 1698 he made a great number of experiments, by order of his serene highness Charles, landgrave of Hesse, in order to raise water by the force of fire, which he communicated to several persons, and particularly to M. Leibnitz, who answered, that the same thought had occurred to himself. He also acknowledged that captain Savery was about that time working upon the same subject in England, and that Savery had first published the fruit of his researches; that from 1698 the affair had lain dormant till the year 1705, when he received a letter from M. Leibnitz, then in London, which contained a draft of captain Savery's engine, and desired Papin's opinion upon it. On shewing this draft to the landgrave, he ordered Papin to resume the work, and perfect the inventions which he had begun; and which Papin then published, not with a view to make it supposed that captain Savery had taken the thoughts from him, but to shew the world its obligation to the landgrave, in having first formed a design so useful, and in having brought it to its present degree of perfection; and he labours much to shew that his engine is preferable to that of captain Savery. Although we must allow Dr. Papin to compliment his patron and himself upon the success they met with, after encountering many unforeseen difficulties and experiments, which succeeded, as he tells us, *quite contrary* to their expectations, yet it cannot be allowed that Papin's experiments in 1698 were the first, because the marquis of Worcester's publication was earlier by no less than thirty-five years; nor were they probable to have been so early as Savery's beginning, since we cannot suppose that he would be at the expence of a patent, without some previous experiments to confirm his speculation, or that he could bring his engine to the degree of perfection in which he exhibited it to the Royal Society on the 14th of June, 1699, in less than a year, at a period when workmen were not ready or skilful in the execution of such machines as they now are in this country.

We have copied the figure of Papin's engine from Belidor, that our readers may be able to compare it with captain Savery's, and judge of the authority upon which M. Boffut has said in his *Hydronamique*, that the first notion of the steam-engine was certainly owing to Dr. Papin, who had not only invented the digester, but had, in 1695, published a little performance describing a machine for raising water, in which the pistons are moved by the vapour of boiling water, alternately dilated and condensed. Now the fact is, that Papin's publication on the steam-engine was in 1707, in which he concedes the invention to Savery. He had occasionally before that published several inventions in the *Acta Eruditorum*, in which cylinders and pistons were to be employed, but they were not intended to be worked by steam, but by gunpowder and air, as we shall shew hereafter.

Description of Papin's Engine.—The intention of Papin's steam-engine was to turn a water-wheel by a stream of water issuing with violence from an aperture or jet, the force of steam being employed to throw the water into an air-vessel, from which it was to issue by the re-action of the compressed air. A spheroidal vessel, A, (*fig. 2.*) of which the longest axis is supposed to be 26 inches, and the lesser axis 20 inches, is placed in a furnace, so that the fire can surround every part: this vessel or boiler, which is made of copper, should be two-thirds full of water, which is introduced by a tube B: a siphon, C D, communicates from the boiler A to a cylinder G H, of 20 inches in diameter, and about the same in height, which performs the office of the barrel of a pump, and in which plays a copper piston, S T, made hollow within, that it may float upon the water: the base of this cylinder, which has no bottom, is joined to the extremity

of a curved tube, I K O, which goes through the bottom of another cylinder, M N, of three feet in height, and 23 inches diameter, which is closed at all parts, so that the air cannot enter. A vessel Y, made like a funnel at the top, is adapted to the tube I K O, and serves to introduce water into the body of the pump G H, beneath the piston S T, which water can never rise above the piston. A cock at E alternately opens and shuts the communication through the siphon C D, between the boiler A, and the body of the pump G H. When the communication is open, the steam formed in A passes into the upper part of the body of the pump, and presses the piston, which displaces the water: this water cannot return into the vessel Y, because a valve at R prevents it; it therefore rises by the tube I K O, and discharges itself into the cylinder M N, where it fills a part of the space occupied by the air contained in that cylinder, which, in consequence, acquires a great elasticity.

As soon as the piston is arrived at the bottom of the body of the pump, the cock F is to be shut, to stop the passage of the steam, and another cock, P, at the top of the body of the pump, is to be opened, to permit the escape of the steam which has performed its office; then the weight of the water with which the vessel Y is always filled, opens the valve R, and introduces itself into the body of the pump G H, and makes the piston S T to rise up again: the water contained in the tube K O is not to be considered in this effect, because a valve at K prevents it from descending. When the water which is introduced into the body of the pump is come to an equilibrium with the water in the vessel Y, the cock P is to be shut, and E is to be opened; the steam comes again to press on the piston, which it forces to descend, and, as in the former instance, expels the water through the tube K O into the cylinder M N, where it cannot introduce itself without surmounting the resistance arising from the elasticity of the air of which it comes to occupy the place.

The cylinder M N, which is three feet high, can contain about 86 cubic feet of water, or about 2.86 cubic feet at every foot in height; therefore, when it is filled to within two feet of the top, the air will be reduced to occupy only one-third of the space in which it was at first shut up, and it will have acquired an elasticity capable of making it sustain a column of water of 64 feet, in addition to the 32 feet with which it is in equilibrium in its ordinary state of compression: under these circumstances, if the cock Q is opened, the water will fly out, at the first instant, with the same velocity as if it was 64 feet high in the cylinder M N; but by degrees, as the water passes out, it will be driven with less velocity, because the air occupying a greater space, its elasticity diminishes: but according to Papin's statement, there should always be at least a foot of water in the cylinder, and the air, in its smallest condensation, should not occupy more than two-thirds of the space which it occupies in its natural state; and in that case it will have a sufficient pressure to sustain a column of 16 feet of water.

M. Papin's machine is, on the whole, far inferior to the engine of captain Savery, as it wants the advantage of the grand principle of condensation, and is only a return to the marquis of Worcester's idea: it cannot therefore be called an improvement on Savery's, although it must be allowed that the separation of the hot steam from the cold water by a diaphragm, piston, or float, is a considerable improvement on the marquis of Worcester's, and would be also an advantageous addition to Savery's, if the condensing water could be as well applied to run down the outside of a cylindrical vessel as an oval one.

Long after Papin's publication, some English engineers made this addition to captain Savery's engine, and attempted

to introduce it in opposition to the cylinder or atmospheric engines, of which we shall hereafter speak ; but the consumption of fuel was too great to balance the advantage of simplicity in the structure of the engine.

Captain Savery must have been employed a considerable time with his machine prior to the 14th of June 1699, and even previous to his patent, as may be inferred from his *Miner's Friend*, printed in the year 1702, where, in his address to the Royal Society, he says, that since the time he exhibited his model to them, "I have met with great difficulties and expence to instruct handicraft artificers to form my engines according to my desire ; but my workmen, after much experience, are become such masters of the thing, that they oblige themselves to deliver what engines they make me exactly tight, and fit for service, and as such I dare warrant them to every body that has occasion for them."

In his address to the gentlemen adventurers in the mines of England, he says, that the frequent disorders and cumbersomeness of water-engines then in use "encouraged me to invent engines to work by this new force ; that though I was obliged to encounter the *oddest* and almost insuperable difficulties, I spared neither *time, pains, nor money*, till I had absolutely conquered them."

Application of Savery's Engine, and its Defects.—Respecting the real use which was made of captain Savery's invention, it appears that a number of small engines were erected, under the authority of the patent, for the supply of noblemen's and gentlemen's seats in different parts of England, and for such purposes they succeeded very well ; but for the supply of towns, and the drainage of mines, where great quantities of water, and great perpendicular pressures were required, they were not well adapted. With respect to the raising water for turning mills, an application which readily suggested itself to the ingenious inventor, we do not think it was ever attempted, for at that period there were scarcely any mills which could have supported the expence of the erection, and maintenance of such engines, even where coals were cheap.

For the drainage of fens they were not well adapted, because the height to which water is most generally required to be raised in such cases is small, and the quantity very great ; on this account several engines would always be wanted for one drainage, and a great part of the power would be lost, because the perpendicular height would be very much less than the height to which the atmosphere would raise the water. To ships we may conjecture that they never were applied, and this reduces their use to a very small compass.

The principal reasons why they could not be so generally employed in mines as the captain was led to expect, and which he laboured to bring about, was, that the working part of the engine must necessarily be placed from 22 to 26 feet above the bottom of the mine ; and if, by any accident, the water should happen to rise above that level, the engine would be drowned and irrecoverably lost, without some other engines to recover it.

As the power of suction in this engine cannot extend more than 26 feet, the rest of the perpendicular lift must be obtained by the expansive force of the steam ; and for every 33 or 34 feet of altitude of this column, a pressure equal to the atmosphere must be exerted on the inside of the boiler and receivers, tending to burst them open.

It is not found practicable, in constant work, to force the water by steam of more than three atmospheres' pressure, or about 67 feet above the engine ; and this limits the whole power of an engine, on Savery's plan, to about 90 feet.

On this account it would require a separate engine for

every 14 fathoms of the depth of a mine, and they must raise from one to another ; but if any one engine is deranged, the rest must stop likewise.

Another difficulty was in the quantity of water which could be raised with safety : the size of his largest boiler did not exceed 30 inches diameter, and the capacity of the receiver could be but small ; and, therefore, the generality of mines would require more than one engine at the same level. The charge, trouble, and difficulty, attending such a number, would naturally prevent their introduction, even in cases where they would really have been of great service. Add to this, the consumption of fuel in Savery's engines was enormous, compared with the modern engines ; and they were always in danger of blowing up, particularly when they were employed to raise water to any considerable height.

Suppose, for instance, the water is to be raised 100 feet ; 25 may be done by suction, and the remaining 75 feet must be lifted by the force of the steam. To effect this, the pressure within the vessel must be more than three atmospheres ; and it will be seen by our table, that every square inch of the interior surface of the boiler and receiver will be pressed with a force of more than 32 pounds, tending to burst them open. This moderate height will, therefore, require very strong vessels, and all the joints must be made with the greatest care ; for although it is true that the pressure is much less than is usual in pumps, and other hydraulic machines, in which there is a greater column of water, yet there is much greater danger of the vessels being burst by steam of such great elasticity, than by an equal pressure of a column of water ; because the force of the steam is always liable to be suddenly increased to a very great extent, on any accession of the heat ; and the heat also tends to weaken the vessels, particularly the boiler, which sooner or later must be reduced in thickness at the bottom, and will then burst.

According to Mr. Dalton's experiments, from which we have formed our tables of the expansive force of steam, it must be heated to a temperature of 287° of Fahrenheit's thermometer, before it can overcome a column of water of 75 feet in altitude ; and as this steam must come immediately in contact with the surface of the cold water in the receiver, which is perhaps as low as 40°, the condensation of the steam is excessive for some time, and must continue until the surface of the water acquires nearly the same temperature as the steam ; which, however, it will soon do, because the heat is transmitted downward very slowly in fluids. When the surface of the water is sufficiently heated, the steam, which before was condensed as fast as it came in contact with the water, will begin to press upon the water ; and as the heat and elasticity increase, it will lift the column. But when it has expelled any of the water from the receiver, a new source of condensation is produced, from the cold surface of that part of the receiver which was before filled with the cold water ; and this condensation will be even more rapid than the former, because the vessel, being necessarily made of metal, will transmit the heat more rapidly than the water did, and delay the process of forcing out the water until the interior surface of the receiver is made as hot as the steam. Captain Savery seems to have been fully aware of this, as he says in the "*Miner's Friend*," that you may see on the outside of the receiver how the water goes out, as well as if it was transparent ; for as far as the steam is contained within the vessel, so far it is dry without, and so hot as scarcely to endure the least touch of the hand ; but as far as the water is, the said vessel will be cold and wet where any water has fallen on it, which cold and moisture
vanish

vanish as fast as the steam, in its descent, takes the place of the water. Also, he says, the force of the steam presses upon the surface of the water, which surface, being only heated by the steam, it does not condense.

Improvement upon Savery's Engine.—The rapid condensation which must take place, when steam of a great elastic force is brought into immediate contact with the water, is an insuperable bar to the raising of water to any considerable height, on Savery's plan. The most obvious improvement was to employ a cylindrical receiver, with a floating piston, in the manner of Papin's; but this was only a partial remedy, because the condensation from the sides of the vessel still took place; and it was not until the piston was made to fit exactly into the cylindrical receiver, and the water kept out of it altogether, that the steam-engine was rendered an efficient machine. But this change, which was invented by Newcomen, introduces much complexity into the work. It becomes necessary to have a separate receiver, with a piston, or, in other words, a pump, to raise the water, and also machinery to communicate the motion of the steam-piston to that of the pump. The simplicity of Savery's engine, and the certainty of its action, rendered it very desirable to obviate its defects so far that it could be employed for mines, even after the more perfect engines were introduced. To avoid returning to the description of Savery's engine, we shall give a brief account of these attempts, before proceeding to the other engines.

The first improvement of Savery's engine was to introduce a small jet of cold water into the inside of the receiver, to perform the condensation, instead of throwing cold water upon the outside of the receiver: by this means a more perfect condensation is obtained, and with a less waste of cold water than by the original plan. The water is conveyed by a small pipe, which branches out from the great forcing-pipe, and enters into the receiver, where it turns down, and terminates with a ball, perforated in all directions, like the spout of a watering-pot, so as to disperse the water in a shower within the receiver. A cock is placed to stop the communication at pleasure; and this cock is opened to admit the cold water, when the steam is to be condensed. But it must be observed, that water cannot enter through this cock into the receiver the first instant that it is opened, because the pressure of the water in the force-pipe must be less than that of the steam within the receiver, and, therefore, the injection will not commence until after the steam-cock is shut, and then the condensation, or loss of heat, which always takes place within the receiver from the coldness of the water, will very soon diminish the heat, and consequently the pressure of the steam so far, that it will no longer balance the pressure of the same column of water, which it had just before lifted into the force-pipe. This being the case, the injection-water begins to run, and falls in a shower through the steam contained in the receiver. The sudden effect of this shower to produce the condensation is really surprising. The injection, being a portion of the same water which has just before quitted the receiver, must have the same temperature as that which was then in contact with the steam; and the difference in the rapidity of the condensation arises only from the dispersion of the water into drops. When the cold water is contained in the lower part of the vessel, the surface only of the water is exposed to the steam, and soon becomes so heated that it will not condense with that great rapidity which it does at first. On the other hand, a quantity of water dispersed in drops will be completely exposed to the steam, and will take up therefrom, in an instant, as much heat as will reduce the temperature of the steam, and increase the heat of the in-

jection-water, until they approach to an equality of temperature. This being the case, it will easily be seen that the degree of condensation which can be obtained within the receiver will be in a ratio to the coldness and quantity of the injection-water; but the quantity required for injection is far less than when applied on the outside of the receiver, because the receiver will not transmit the heat of the steam through it so quickly, but the water must run down the outside of the receiver, and descend into the well, without being much warmed, and without having extracted much heat from the steam within.

The next improvement in Savery's engine was the addition of the safety-valve to the boiler. This was invented by Papin for his digester, to permit the steam to escape from the boiler into the open air, when it arrives at such a degree of pressure as to endanger the rupture of the vessels. The safety-valve, which is shown in the figure of Papin's engine, *fig. 2*, is nothing more than a valve opening outwards, and well fitted to close an aperture which is made in the top of the boiler, and is kept shut by a weight or a lever, which is loaded with a weight, capable of standing upon the lever in the manner of a steelyard; so that the pressure of the weight upon the valve can be regulated at pleasure, according to the strength of steam which is required: but, in all cases, it must be loaded so as to permit the steam to lift it up and escape, when it arrives at a pressure which would endanger the boiler or receiver. With a view to strengthen the boiler, hoops and internal radiating bars were tried, according to the idea of the marquis of Worcester; but this was found of very little service, because, on account of the condensation of the steam, it is much better to divide the mine into engines of from 70 to 80 feet lift, according to captain Savery's first proposition, than to attempt using steam of that degree of elasticity, which will require any such precaution.

In the Philosophical Transactions, N° 461, there is an account of a new way of producing steam of a great pressure. The boiler consists of an inverted conical vessel of iron, to the base or upper part of which a close and strong copper-head or hemisphere is joined by rivets all round: the lower part, or cone, is set in a reverberatory-furnace, to receive a sufficient heat from the flame to make it red-hot. The water is introduced into this boiler in a number of small streams, or jets, which are injected into it by a pipe, which descends through the cover, or spherical top, of the boiler; and in the middle of the cone several spouts are fixed, radiating from it like the arms of a wheel: the pipe must be carried up above the boiler, so as to have a column of a sufficient height to overcome the pressure of the steam, and also enter into the boiler with a considerable force; and by the radiating spouts it is dispersed in a shower upon the interior surface of the iron cone, and is thus converted into steam, which flies up to the copper-head, and is carried off by a pipe to the engine. The inventor proposed to make the tube with the radiating spouts to revolve, for the purpose of distributing the water more completely; but he probably never tried the experiment, or he would have found that the boiler would have been soon destroyed by the rapid oxydation of the iron which must take place from throwing water upon it when red-hot; and copper would have melted.

In 1717, Dr. Defaguliers made an engine on Savery's plan in an improved form. He says, that in considering Savery's engine with Dr. Gravesande, they thought there was a great waste of steam, by its constantly acting upon the receivers without intermission, the steam becoming useless until it had heated the surface of the water in the receiver, and also to a certain depth below the surface: but

if it were so contrived, that after the steam had pressed up one receiver full of water, instead of being thrown into another, it should be confined in the boiler till the receiver was refilled by the atmosphere, and thus turned upon the water, the steam would have acquired so much force from its confinement, that it would press suddenly upon the surface of the water, and discharge a considerable portion of it even before it had heated the surface. In pursuance of this idea, they had a model made which could either be used with one or two receivers, and found, on experiment, that one receiver could be discharged three times in the same time that two could be discharged once. They also learned that captain Savery had made an engine at Kensington with only one receiver, which acted very well. Defaguliers then made several engines with a spherical boiler, provided with a safety-valve, and a receiver of about one-fifth of the capacity of the boiler, and of a cylindrical figure, tall, and of small diameter in proportion. The steam and the injection-water were alternately admitted into the receiver at top through a double-passaged cock, the handle of which being turned towards the boiler, admitted steam; or, being turned towards the force-pipe, admitted the jet of cold water; but only one of these passages could be open at the same time. The small branch from the force pipe which conveyed the injection-water to the double-passaged cock, had another cock in it to adjust the aperture, and regulate the quantity of water which should flow into the receiver. The suction-pipe and force-pipe were the same as Savery's; but the valves were conveniently situated, so as to be readily accessible when they required repairs. Dr. Defaguliers tells us that he made seven of these engines: the first was for the czar Peter the Great, for his garden at St. Petersburg, where it was set up. The boiler of this engine was spherical (as they were all in his way where the steam was so much stronger than air), and held between five and six hogheads; the receiver held one hoghead, and was filled and emptied four times in a minute. The water was drawn up by suction, or the pressure of the atmosphere, twenty-nine feet high out of the well, and then pressed up eleven feet higher. The pipes were all of copper, but foldered to the suction-piece with soft folder, which held very well for that height; but he did not venture either upon a greater quantity for that height, or a greater height for that quantity; for if the quantity was larger than above, the boiler must have been greater, and the steam of the same force would have had a greater surface to act upon, which might have burst the boiler, or would have required it to be made much thicker.

Another engine of this sort, which he put up for a friend in 1730, drew up the water twenty-nine feet from the well, and then it was forced up by the pressure of the steam twenty four feet higher, into a cistern holding about thirty tons, placed at the top of a tower, in order to run down again through a pipe or conduit, and play several jets in the garden. But sometimes, no jets being played, the water was discharged at the height of six or eight feet out of the force-pipes to fill the ponds and water-meadows in dry weather, which it did with a less strength of stream than what drove the water into the tower; or if the same steam was kept up, it would make eight or nine strokes in a minute, instead of about six, as when the water was driven up into the cistern. Upon the safety-valve there was a steelyard, the place of whose weight shewed the strength of the steam, and how high it was capable of raising water; but when the weight was at the very end of the steelyard, the steam, being then very strong, would lift it up and go out at the valve, rather than damage the boiler. Twenty-

five years after this engine was made, a man, who was entirely ignorant of the nature of the engine, without any instructions, undertook to work it; and having hung the weight at the farther end of the steelyard, in order to collect more steam, to make his work the quicker, as also a very heavy plumber's iron upon the end of the steelyard, the steam not being able to lift the safety-valve, the steelyard, loaded with all this unusual weight, burst the boiler with a great explosion, and killed the poor man who stood near with the pieces that flew asunder.

These accounts shew how high, and in what quantity, this kind of fire-engine can safely raise the water. About as much fire as a common large parlour-fire was sufficient to work this engine, and raise fifteen tons *per* hour; so that if the cistern was kept full, the jets could be made to play to entertain friends at any time, and then a man being sent to light the fire under the boiler, the engine would raise water to supply the jets before the cistern was empty.

M. De Moura, of Portugal, sent an engine to the Royal Society upon the principle of Savery's, but provided with apparatus to make it self-acting, and to open and shut the valves at the proper instant. The receiver, boiler, steam-pipe, and injection-cocks, are the same as we have before described, together with the suction and forcing-pipes, and their valves. What is peculiar to this engine is, a float within the receiver, composed of a light ball of copper, which is not loose therein, but fastened to the end of an arm or lever, which is made to rise and fall by the float, while the other end of the arm is fixed to an axis, and consequently, as the float moves up and down, the axis is turned round one way or the other. This axis is made conical, and passes through a conical socket, which is foldered to the side of the receiver, and upon that end of the axis which projects beyond the socket; and, therefore, at the outside of the receiver is fitted a second arm, which is also moved backwards and forwards by the axis, as the float rises and falls. By these means, the rising and falling of the surface of the water within the receiver communicates a correspondent motion to the outside, in order to actuate the rest of the gear, which regulates the opening and shutting of the steam and injection-cocks. A small cistern is foldered to the outside receiver, and, being kept full of water, surrounds the joint, or conical socket, through which the axis of the float passes: this keeps the axis and socket airtight. The cistern is constantly kept full of water by means of a small leakage from the force-pipe, through a wooden peg, and the drops are conducted by a packthread down to the cistern. A small weight is applied to the arm on the outside of the receiver, to counterpoise the float within; also upon the same arm is a slider, which being set nearer to, or farther from the axis, will rise or fall a greater or less space, as may be required; when the float within rises or falls, and the slider can be fastened by a screw at any part. A chain is attached to the slider, and gives motion by means of a shorter chain to a balance, or tumbler, which moves on an axis, and opens and shuts the cocks. The first-mentioned chain passes over two pulleys, supported by two arms, that are fastened to the side of the receiver, which give a chain a proper horizontal direction: in order to move the balance to the end of the chain, a weight is fastened sufficient to raise the balance to a perpendicular position, and also to overcome the friction of the float, and its axis with the pulleys and chain.

The balance moves upon an axis, which is supported in pieces projecting from the receiver; and it has three arms, one of which applies with a roller to the handle of the steam-cock, a second acts upon the lever of the injection-

cock, and a third short arm has a piece of chain, to link it to the chain before-mentioned, at the part where the same extended horizontally between the two pullies. The arms, which act upon the cocks, are so placed, as to shut the steam-cock the moment before the injection is opened, and *vice versa*.

To put the engine in motion, press down the arm of the axis, which raises the float within the receiver, and the counter-weight of the chain will bring the balance over to the right side, and in its motion will open the steam-cock, and shut the injection-cock: also open a small gauge-cock in the top of the receiver, that the air may be discharged by the entrance of the steam into the receiver. This being done, shut the air-cock, and let go the arm of the balance: the weight at the end of the chain will bring over the balance to the left, and in its motion will shut the steam-cock and open the injection-cock, to admit a small jet of cold water into the receiver, which presently condensing the steam into water, in a great measure leaves a vacuum in the receiver. In this situation the pressure of the atmosphere will cause the water to mount through the suction-pipe into the receiver, where, as its surface rises, it makes the float ascend, and depressing the arm on the outside of the receiver, draws the chain and raises the balance, till it has passed the perpendicular, when it will fall over suddenly by its own gravity: in falling, the roller of one of its arms takes hold of the handle of the steam-cock, and opens it, whilst the other one shuts the injection-cock. This fall of the balance takes place when the receiver is almost filled with water, and the balance cannot return till the surface of the water therein subsides, and suffers the float to descend. This takes place as soon as the steam ceases to be condensed by the cold receiver, and acquires sufficient elastic force from its heat to fill the receiver and drive out the water from the forcing-pipe. When the surface of the water descends the float sinks, and suffers the counter-weight to draw up the chain. By the short chain it draws the balance beyond the perpendicular towards the left, when it falls of its own accord; and in falling, the one arm takes hold of the handle and shuts the steam-cock, whilst the other opens the injection-cock, as before.

In the "*Machines approuvées par l'Académie for 1744*," is a description of an engine by M. Genl'anes, which very closely resembles M. De Moura's, but is more completely described.

Mr. Blakey's Engine on Savery's Principle.—Long after steam-engines superior to Savery's had become general, an ingenious engineer, Mr. Blakey, made many attempts to introduce Savery's engine in an improved form. He obtained a patent in 1766, from the specification of which it appears, that his improvement was to employ oil floating upon the surface of the water in the receiver, to form a piston or disk between the hot steam and the cold water, to prevent the steam being condensed as soon as it touches the surface of the water; or air was to be admitted into the receiver for the same purpose. In this case, two receivers were to be used, one in the same situation as Savery's, which was to receive the air; and the hot steam, when admitted into it, forced the air to descend by a pipe to the second receiver, which was at the bottom of the well, and expel the water therefrom, and elevate it in the force-pipe. By this means he hoped to prevent the steam coming in contact with the water, and avoid the condensation.

Mr. Blakey afterwards made some alteration in the form of his engine, which is described as follows by Mr. Ferguson: (see *Plate I. fig. 3.*) E is the boiler, set in a furnace so as to be surrounded with flame: F is the gauge-cock, to ascertain the depth of water in the boiler: D the steam-

pipe, to which is foldered the cock and funnel C, for filling the boiler before the engine is set to work: I is an air-vessel, and T T an injection-pipe, which passes through across the top of the receiver, and has small holes pierced in it for the cold water to drop through and fall in a shower in the air-vessel I, in order to form a condensation: the end of the injection-pipe is carried into the steam-pipe D, to admit a small quantity of water to run down the pipe D, and supply the boiler: V is a receiver, communicating with the air-vessel I by a pipe; in the upper part of it is a cullender S, with small holes to disperse the injection-water, which falls from the air-vessel I, equally through the receiver V: O is a valve to admit air, which comes through the cock P into the receiver; and H is an occasional cock, to let out the air and steam when the engine is first set to work: Q is a pipe from the receiver V, to the box which contains the valves B and N at the bottom of the forcing-pipe A, which conveys the water up to the reservoir: M is the suction-pipe, to draw the water from the well up to the receiver: G is the fire-place belonging to the furnace, in which the boiler is set, and beneath it is an ash-hole. It is needless to say any thing of the scaffold or the well, they being always made according to the size of the machine, and in proportion to the place in which it is to be erected. All the vessels and pipes of this engine are made of strong copper.

In order to set this engine at work, the reservoir and pipe A must be filled with water, which will be retained in the clack B; then more water must be poured into the funnel C, which is on the steam-pipe D; from thence it falls into the boiler E, and rises to the level of the cock F, which must be open; but as soon as the water runs from it, the funnel-cock C, as well as the gauge-cock F, must be shut, and the air-gauge cock H must be opened. The fire is then to be put into the furnace G, and as soon as the water is in ebullition in the boiler it creates steam, which finds its way through the pipe D, and forces the air out of the vessel I into the lower receiver V; the air is also forced out at the cock H, the steam following it with great velocity. In a second or two the cock H must be shut, and instantaneously the injection-cock L must be opened, which lets cold water run through the end of the pipe T T, into the steam-pipe D, to replace that which has been evaporated out of the boiler E; and it also rushes out on all sides from the little holes which are in the sides of the pipe T T, into the air-vessel I, and falls on the cullender S: this cold water makes a sudden condensation in the vessels I and V, and forms a vacuum, which causes the atmosphere to press on the water in which the lower end of the pipe N is immersed, and the water ascends the said pipe with great rapidity, and passes through the clack N, and through the pipe Q, into the receiver V, till it rises up to O, where is a floating-ball fastened to a handle or lever, which in rising turns the key of the cock P, and opens it: there is a valve at that end of the cock which is withinside of the receiver V, so that as soon as the cock is opened, the valve O is forced up by the air, which rushes through with great quickness and noise into the vessel I; and when that vessel is full of air, the vacuum is destroyed and no more noise is heard, which gives the notice to shut immediately the injection-cock L: that being done, the steam recovers its force, and makes its way through the steam-pipe D, into the air-vessel I; and as the steam increases, being much lighter than air, it keeps uppermost, and forces the air on the water which is in the receiver V, which water is forced through the pipe Q, and lifting up the clack at B, goes up the pipe A, and empties itself into the reservoir at top. When all the water is expelled out of the receiver V, the air follows, and ascends

with great velocity through the water which is in the pipe A : two or three seconds after the noise of this is heard, the injection-cock L must be opened to let in cold water, and cause the same effect as before. The noise of the air rushing in and out of the receiver gives proper notice when the manager of this hand-engine is to open and shut the injection-cock, which is the only thing required to work this machine, when once it has been put in action, in the manner that has been described above.

This engine was not found to answer any better than Savery's, because the air will not make that complete separation between the steam and the cold water which the inventor expected; and there is a great loss of power to compress the air sufficiently to make it lift the column of water; and in order to get rid of this air it must be forced up the pipe, which takes as much power of steam as would be required to force up as much water as the air occupied the place of when in its condensed state. Mr. Blakey's intention in the injection of a small quantity of water into the boiler at every stroke, was the same as Mr. Payne's red-hot boiler, of which we have before spoken, but he was in practice obliged to employ a steam-cock in the pipe D, otherwise the steam which the boiler produces whilst the injection-cock is open would have been all condensed and lost.

Savery's engine can be usefully employed for lifting water 30 or 35 feet, which can be done principally by the suction, and with a very slight pressure for the remainder; but it is the most advantageous way to raise no more than 24 feet, and perform the whole lift by the suction, and even to allow the water a sufficient descent to empty the receiver by its own gravity, without forcing it in the least by the steam. In this form of the engine, the steam need have no greater elastic force than the atmospheric air, or just as much as is sufficient to make it enter into the receiver, as the water runs out. The temperature of the steam, according to our table, will then be only a little above the boiling point, or above 215° , and consequently the loss by the condensation is not so serious; and as the steam is not pressed upon the water, it is not brought into such close contact with the cold water, as in the forcing engines. In this way, the injection must be forced in by a small force-pump.

Mr. Kier's Engine on Savery's Plan.—An engine upon this principle, with various judicious improvements, was erected some years ago by Mr. Peter Kier, at his manufactory of coach axletrees, near Pancras, where, without any material repair, it has almost constantly been worked since, to raise water and turn a water-wheel. The proprietor states it to answer his purpose very well, because it works without an attendant, and regulates its own motions; and, as might naturally be expected, the wear and tear are also inconsiderable.

Plate I. Steam-Engine, fig. 4. represents this engine, taken in a section through the centre. R represents an oval boiler, seven feet long, five feet wide, and five deep. Mr. Kier considers it as being of dimensions sufficient to work a larger engine; a circumstance which must, in a certain degree, increase the consumption of fuel. It feeds itself with water conveyed through an elevated pipe, at the end of which is a valve. This valve does not open until the fall of the water within the boiler has suffered a float to subside, which by its actual weight affords to draw the valve open; but the float, by its tendency upwards, as the water in the boiler rises, serves effectually to close it. The water in the boiler, therefore, remains constantly at or near the same level. The steam is conveyed by a pipe, T A V, to a box B, through which, by the opening and shutting

of a valve, it can be conveyed to the working chamber E. The axis, C, serves as a key to open and shut the valve: N O is a cistern of water, from which the engine draws its water through a vertical pipe, in which the valve Q is placed, to prevent the return of the water; G G is another cistern, into which the water is delivered through the pipe F, which is provided with a valve H, opening outwards; I M represents an overshot water-wheel, 18 feet in diameter, moving on the axis K L, and communicating its motion to the lathes, and other machines used in the manufactory. The water in both the cisterns becomes warmer than the hand, after working a short time; for which reason, the injection-water is forced up by a small pump from a well, supplied from the small stream on which these works are established. A leaden pipe passes from this forcing-pump to the upper or conical part of the chamber E, for the purpose of injecting cold water at the proper time. Neither of these could be represented with convenience in the present section.

The manner in which the steam and cold water are alternately admitted into the chamber E, remains to be explained. Upon the extremity, K, of the axis of the overshot water-wheel there is fixed a solid wooden wheel, about four feet in diameter: it is also represented in *fig. 5*, as seen in the front; *a, b, c, d*, are four cleats, all or any number of which may be fixed on the wheel at a time. Each cleat has its correspondent block, *e, f, g, h*, on the opposite surface of the wheel. The use of these is to work the engine. Suppose the wheel I M K, with all the revolving apparatus, be turned round by hand, one of the cleats meets in its rotation with a lever, which opens the steam-valve by a bar of communication reaching to the handle of the axis C, *fig. 2*. The steam consequently passes into the chamber E, and the steam-valve shuts again, as soon as the cleat has passed. Speedily after this, the correspondent block on the other side of the wheel meets another lever, which is similarly attached to the handle of the forcing-pump, and, therefore, throws a jet of cold water into the chamber, and condenses the steam. The pressure of the atmosphere then forces the water from the cistern N O, through the valve Q, towards the chamber E. When the engine has been long out of work, two or three strokes may be necessary to raise the water to the top of the chamber E. As soon as this is the case, the re-entrance of the steam suffers the whole body of water, above the valve H, to flow out of the chamber E, by its gravity.

The water which is raised is suffered to flow upon the overshot water-wheel, I M, through a sluice; and by that means keeps the work in motion, and replenishes the lower cistern. There is no reservoir for the injection-water, but the requisite quantity is driven up at each stroke.

Hence we see, that in effect this engine is the same as Savery's original engine, except that it is not applied for the immediate purpose of raising water, but gives motion to other apparatus; and it does not force the water by the steam at all. The water merely falls out of the chamber, and consequently never requires steam much stronger than the atmosphere. From the effect of this engine, under circumstances of such advantage, it may fairly be concluded, that the action of steam against water in forcing can never be beneficial, except at places where fuel can be had extremely cheap. It was found, at the first erection of this engine, that the consumption of steam, by contact with the water, was so great, that it could not be worked with advantage. This defect was remedied in the present engine, as well as in another which was at Norwich, by fixing a small air-valve in the steam-box, which is struck open by the machinery for an instant, immediately before the ad-

mission

million of steam. It may be presumed, that, according to Mr. Blakey's idea, the air occupied a space above the water, and prevented their coming together. Mr. Kier, however, is disposed to think that the effect does not take place in this manner, but by some mixture and dilatation of the two fluids; because he imagines the mischief from the wet surface of the cylinder would remain the same, when the water descends. To get rid of this air, the steam in the boiler must be made so much stronger than the atmosphere, as to rush into the receiver with sufficient force to drive out the air through the same valve at which it entered, and which opens outwards for that purpose; but will shut, to prevent the air entering when the vacuum is made, except for an instant before the steam is admitted, when it is opened by the machinery. The motion of the overshot water-wheel is regulated by an apparatus called a governor, invented by Mr. Watt, and which will be described in our account of his engine. It is a perpendicular axis, which revolves by communication with the engine, and carries round two pendulous balls; which pendulums move on a joint, fixed to the vertical axis. When the rotation is very quick, the balls fly out, and are applied to draw down a lever, which is connected with the sluice of the upper cistern: the sluice, therefore, is made to fall or rise, according as the velocity of the engine is greater or less. By this disposition, when the wheel moves very speedily from lightness of work, or any other cause, the quantity of water thrown down from the upper cistern is immediately diminished; and, on the contrary, the quantity of water is rendered greater, when the slowness of the movement shews that more is wanted.

The engine here described has been at work many years, and from the simplicity of its construction has yet exhibited no proofs of wear.

Mr. Kier thinks it a profitable engine to himself, and that it would be serviceable for raising water where coals are cheap. It consumes six bushels of good coals in twelve hours' work, when in its best state, or seven bushels when at the worst. Under these circumstances it gives ten strokes *per* minute, each throwing out seven cubic feet of water at an aperture of 20 feet above the water beneath. This quantity, namely, 70 cubic feet *per* minute, will weigh 4375 lbs. raised 20 feet high, which being doubled, to reduce it to Desaguliers' standard height of 10 feet, will amount to 8750 lbs. raised 10 feet high; and this divided by 550, the number of pounds in a hoghead, will give a quotient of 16 hogheads raised 10 feet, representing the force of 10 many men, according to the estimate of that author, who reckons five men equivalent to one horse. The result is not quite half what is performed, with an equal quantity of coals, by the improved engines, with a piston of such size as to be equal to 20 or 25 horses. *Philos. Journ.* vol. i.

Several other engines have been erected upon this plan; and where the water which is raised is to be immediately boiled, they are very capital machines, because all the loss of heat is thrown into the water and warms it before entering the boiler, so as to economize the whole: for instance, for the purpose of raising water into the boilers for a salt-work or for a brewery, they are very applicable.

We have no accounts of the quantity of water which could be raised by Savery's original engine with a given quantity of fuel; but he tells us in the *Miner's Friend*, that to lift a three-inch bore of water 60 feet high, would only require a fire-place for the furnace of 20 inches deep, and 14 or 15 wide; the expence of fuel for which, he says, would be inconsiderable, when compared with the advantages to be derived from the use of the engine.

It has been proposed to construct a succession of engines

upon Savery's plan in a mine, to raise water by suction from one to another, and to have all of them worked by one common steam-boiler. For this purpose, the depth of the pit is divided into lifts of about 15 feet, and at each lift is a cistern, to receive the water raised by the different engines. Each engine consists of a vertical suction-pipe, with the lower end immersed in the water of the cistern of the engine below it, and a receiver at the upper end, which communicates with the suction-pipe through a valve, to prevent the descent of the water from the receiver through the suction-pipe. There is also a small spout or pipe leading from the side of each receiver into each cistern, which is to receive the water after it is raised into the receiver; and the ends of these spouts are covered with valves, to prevent the water running back into the receivers from the cisterns. All these receivers communicate with a common air-pipe, which leads up to the top close receiver, or air-vessel, situated at the top of the pit, which vessel is of at least double the capacity of all the receivers and the common pipe together. Immediately above the air vessel is the steam-receiver, of equal capacity, and communicating with the air-vessel by a pipe, which descends through the top of the same, and reaches nearly to the bottom of the air-vessel, so that if there is any water in this vessel, the end of the communicating pipe will be immersed therein.

Suppose the cisterns at the different stages, and also the lower or air-vessel, nearly filled with water, and the air-pipe and the small receivers filled with air, the action of the machine will be as follows: the steam is admitted from the boiler into the upper receiver, and expels the air therefrom through a proper cock or valve: when thoroughly filled with heated steam, the communication with the boiler is shut, and an injection of cold water thrown into the receiver; this condenses the steam, and forms a vacuum in the upper receiver: this being the case, the air contained in the air-pipe and receiver, by its elastic pressure upon the surface of the water contained in the great air-vessel, causes the water to mount through the pipe of communication into the upper or steam-receiver. This causes the air in the pipes and receivers to occupy a greater space than it did before, and being thus rarefied, it no longer balances the pressure of the atmosphere upon the surface of the water contained in each cistern; it therefore forces the water up the respective suction-pipes into the small receivers, and will fill each of them one half with water, and then the air contained in the remaining half of each receiver, and in the great air-vessel above, comes to its equilibrium. The steam is now admitted a second time into the steam-receiver, and pressing upon the surface of the water therein, allows it to descend by its gravity into the air-vessel beneath, from which it expels the air, and by the communication of the air-pipe it enters into the upper part of each of the small receivers down in the pit, and bearing upon the surface of the water in each, suffers it to flow out by its own weight through the spouts into their respective cisterns. When they have thus discharged the water which they had before drawn up, the steam in the upper receiver is again condensed, and this rarefies the air in the air-vessel and several receivers, and draws up more water from each cistern; and thus the action of the machine continues as long as the boiler affords steam. In this plan, the water in the upper receiver is never changed; but the same water is constantly subjected to the action of the steam, and will thereby become heated so as to avoid the loss of steam by the condensation. But this at the same time introduces another difficulty, which the inventor had not foreseen, *viz.* that the heat of the water will prevent a sufficient condensation

of the steam to obtain a vacuum: for instance, it is not necessary for an engine of this kind to have steam in the boiler of much greater pressure than the atmosphere: suppose it is equal to raising water two feet, by our second table this will be at a temperature of 215° . Now, according to our first table, in order to obtain such a degree of rarefaction of pressure within the receiver as to lift a column of 30 feet of water, the temperature must be cooled down to 120° ; therefore, at every stroke of the engine a change of temperature must be made equal to 95° , viz. between 120° and 215° . On this account, such an engine would require a great quantity of condensing water, and it is probable that it would be better to make the water, which the engine raises, pass through the receiver, on Savery's plan, or at least such a portion of it, as will keep the temperature of the water in the receiver sufficiently low to obtain the condensation which we have above mentioned.

In employing air in this manner to transmit the force of the steam into other vessels, there is always the loss from the elasticity or compressibility of the air, which, in the case above stated, will be equal to one-half; because, when a sufficient rarefaction is made within the steam-receiver to cause the atmosphere to press upon it equal to 13lbs. upon the square inch, or to suck up water 30 feet, the air contained in the air-vessel and pipes will expand itself so as to balance one-half of that pressure; and, therefore, the degree of rarefaction within the small receivers will be only sufficient to raise the water 15 feet instead of 30. On the other hand, when the steam is admitted into the receiver, it must be in sufficient quantity to restore the air to its original density, before it will balance the pressure of the atmosphere, and allow the water to flow out of the receivers into their cisterns.

Fig. 5. represents a similar contrivance to the above, but it is for forcing. It was suggested by Mr. Kier, in 1783. A is a boiler, and B a steam-vessel: this last communicates with the vessels M, L, K, T, each of which, except the lower one, consists of two vessels; first, an external cistern, open at the top; and secondly, an interior receiver, immersed in the water of the cistern, and closed on all sides, except where it communicates with B, by the branches of the receiver, the pipe F G H descending from B, and where the pipes P, O, N, I, enter the upper part of each, and descend within nearly to the bottom, and also where there is a valve at the bottom opening upwards. If steam be let pass from A to B, the air will be driven from B through the pipes F, and press upon the surface of the water in the lower receiver T, and drive the same up the pipes into the vessel or cistern K, but not into the receiver K, because the pressure of the air within that receiver keeps the valve in the bottom of the receiver shut. The next step of the operation consists in closing the cock C, and opening D, out of which a portion of steam will be driven, by the re-action of the water forcing itself through the valve in the bottom of the receiver T, from its natural tendency to rise to the same level as the surface of the water in the pit well; and on the same account the water will enter into the receiver, K, from the cistern in which it is immersed: the cock D is then to be closed, and C opened; in consequence of which, the contents of the receiver, T, will be forced up to the cistern, K, by the steam, as before, and the receiver, K, will discharge its contents through the pipe, N, into the cistern L.

The steam being again shut off at C, and the cock D being opened, as before, the receivers, T, K, and L, will fill as before, by the water from the exterior cistern entering through the valves in their bottoms, and a larger por-

tion of steam will issue from D. A third repetition of the process will drive the contents of these three receivers a step higher; and a fourth repetition will cause the contents of the upper receiver, M, to flow out at P; after which, every alternation of the work with the cocks C, D, will throw out the same quantity from P.

The vessel B must necessarily contain a quantity of air capable of occupying the whole interior space contained in the closed receiver, with an allowance for the loss of bulk in condensation, under the pressure of a column of water equal to one of the lifts; and the quantity of steam to be discharged at each stroke, must occupy a space equal to that of all the water moved at each stroke; and must, in all cases, be considerably stronger than two atmospheres, in proportion to the heights of the lifts.

Other Proposals for the Improvement of Savery's Engine.—In the Memoirs of the Philosophical Society of Lausanne, M. Francois has described a steam-engine on Savery's plan, which he proposes to be used for draining fens or marshes, and has added machinery to open and shut the cocks; it has otherwise nothing remarkable. See Repertory of Arts, first series, vol. iv.

In the American Philosophical Transactions there is a description of a steam-engine, on Savery's principle, by Mr. Nancarrow, which is applied to raise water for turning a water-wheel. In this engine, the receiver, into which the steam is admitted, is a tall cylindrical pipe, with only a slight enlargement at the top to form the receiver; and the water is only raised by the pressure of the atmosphere: and to prevent the water being changed and continuing cold, so as to condense the steam, it is not suffered to run off immediately from the receiver, as in Mr. Kier's engine, but nearly at the bottom of the tall cylindrical pipe it is joined to a box, as shewn by the dotted lines in the figure of his engine, and from this box a second vertical pipe, or force-pipe, ascends to the reservoir which contains the water: the valve to prevent the return of the water is placed at the lower end of this second pipe.

By this means, the portion of water which comes in contact with the steam rises and falls in the receiver, and alternately draws and forces other water through the box below, from the suction-pipe, and into the force-pipe and reservoir. But this water, when it becomes heated, acts like a floating piston on the surface of the cold water to prevent the contact of the steam. Mr. Nancarrow proposed to employ a separate condenser and air-pump to produce the vacuum, instead of making an injection into the receiver; but this would be attended with no advantage; and we have before stated the objections to the water growing heated any more than superficially.

At the same time we think that a very good and simple engine might be made, if this form of the apparatus, in which the water shall never be changed, was applied to forcing by the pressure of the steam only, on the plan of Worcester's plan, and not to attempt condensation, which it is impossible to effect perfectly, when the water has become very hot; but instead of proof, when the steam has exerted its force, to open a cock, and let off the steam into the open air. An engine of this kind, which only requires the additional receiver, is described in Leupold's *Theatrum Machinarum Hydraulicarum*, vol. ii. 1724.

The last improvement which we have noticed in Savery's engine, is by Mr. James Boaz, of Glasgow, who took out a patent in 1805, for several different forms of the engine. In all these the receiver is made cylindrical, and a piston is applied to float upon the surface of the water, upon Papin's plan; and in the same manner as Nancarrow's engine.

he proposes to employ such an arrangement of the force-pipes, and of a second small receiver, that the water which comes in contact with the steam shall not be changed, but shall always remain the same; a method which precludes the use of the vacuum by condensation. The specification of this patent is published in the Repertory of Arts, vol. viii.

Newcomen's, or the Atmospheric Steam-Engine.—This engine is named after its inventor, Mr. Thomas Newcomen, an ironmonger of Dartmouth, in Devonshire. He appears to have been a person of ingenuity, and of some reading, and was acquainted with the famous philosopher Dr. Hooke. Newcomen was in the habit of visiting the mines of tin and copper in Cornwall, where captain Savery was well known, from his attempts to introduce his engine for the draining of mines, which, at that period, were nearly all of them at a stand, for want of some more powerful and cheap machines than hand-pumps or horse-machines.

The captain was not successful in his attempts, principally because he employed the direct action of the steam upon the water, which either confined him to the height of 25 feet, or compelled him to employ steam of a great elastic force; in which case it became an indispensable condition, that the boiler and vessels should be very strong, as well as that a large quantity of fuel should be consumed, to produce steam sufficiently dense. It is probable that these inconveniences may have early directed the thoughts of other ingenious men to the application of a piston; but the difficulties of the undertaking seem to have retarded this pursuit for a considerable time.

The first steam-engine with a piston, made by Papin in 1707, which we have described, was not at all calculated to remove the difficulties; and it is to Newcomen, and his associate Cawley, that we are indebted for the application of a piston with machinery, by which the indirect action of steam a little stronger than the atmosphere, or rather the direct action of the atmosphere upon a piston, is made to act with safety and effect against the most severe pressures. It appears that they had brought their atmospheric engine, about the year 1713, to a degree of perfection little inferior to those which are to be seen at present.

Principle of the Atmospheric Engine.—To have an idea of its principles and mode of operation, suppose a very large syringe or cylinder to be placed upright, and a piston or plug inserted at the upper end, the usual aperture being supposed to be at the lower extremity. If this last aperture is open, the piston will descend by its own weight, neglecting the effect of friction at its circumference. But let it be imagined that the piston is supported by a counter-weight applied at the opposite extremity, a lever, or by any other means: in this case the piston will not descend unless more weight is added to it.

Among the various ways of applying such a weight, there is one which consists in exhausting the air from the internal part of the cylinder, beneath the piston: and if this is done, it is evident that the whole pressure of the atmosphere, amounting to about $14\frac{1}{2}$ pounds on every square inch, will become active upon the upper surface of the piston. This method of gaining a great force was invented by the famous Otto Guericke: see his *Experimenta Magdeburgica*, 1672. If the vacuum was to be produced by means of an air-pump on Guericke's plan, it must be allowed that the labour of effecting it would be at least equal to that of any work which could be performed by the subsequent descent of the piston; we must therefore seek some other means of producing such a vacuum. We have seen that in Savery's engine the operation of steam is two-fold, namely, by the direct pressure from its elasticity, and by the indirect conse-

quence of its condensation, which affords a vacuum. This last is the only principle employed in Newcomen's engine.

In order to produce the vacuum at pleasure in the interior capacity of the syringe or cylinder, of which we have been speaking, it becomes requisite that several apertures should be formed at the bottom of the cylinder; one to communicate steam from a boiler, and provided with a cock to cut off or open the communication at pleasure; another to admit at pleasure a jet of cold water, to condense the steam during the interval in which the communication from the boiler is cut off; a third, provided with a drain-pipe, called the eduction-pipe, to carry off the condensed steam and injection-water; and lastly, a small lateral aperture, with a valve, to allow the escape of the air, or permanently elastic fluid, which will not condense by the application of cold water, or run off through the eduction-pipe: this last is called the snifting-clack.

By these provisions the operation of the cylinder is made to take place in the following manner. The piston-rod is attached by a chain to the end of a long lever, at the opposite end of which are suspended the rods of the pumps which are to draw the water; and the weight of these rods exceeds the weight of the piston so much, as to draw the piston up to the top of the cylinder. In this state, the steam-cock is opened, and steam issues from the boiler; but being less than half the weight of common air, it rises to the top of the cylinder, and expels the air through the snifting-valve and eduction-pipe, of which the lower extremity is covered with a flap-valve, in a trough of water. When the noise of its escape through these valves is heard, the steam-cock is shut, and the injection-pipe being opened, throws up a stream of cold water in a jet within the cylinder, and strikes against the bottom of the piston: the steam becomes immediately condensed, and the pressure of the atmosphere forces the piston down into the vacuum. Upon its progress downwards, the injection-pipe is closed; and when it has arrived nearly at the bottom of the cylinder, the steam-cock is again opened. The elastic steam fills the small space between the cylinder and the bottom, and its pressure on the under surface of the piston assists it to rise, and also assists the eduction-water which remains in the bottom of the cylinder to pass off through its pipe: the steam also drives the air, or other elastic fluid which will not condense, through the snifting-valve. In this state, therefore, the steam is somewhat stronger than the atmosphere, and rather more than counterpoises its action on the upper surface of the piston; in consequence, the piston itself rises by the action of the counter-weight, or pump-rods, at the opposite end of the lever, and regains its original position at the top of the cylinder.

A second repetition of the process, namely, of shutting off the steam, and injecting cold water, causes the piston again to descend, and in this manner the alternations may be continued without limit.

It is to be understood, that the opening and shutting of the steam and injection-cocks are performed by apparatus fixed to the working lever, in such a manner as to strike the levers of those cocks at the precise instant of time when their effects are required to be produced. The attendant has no other office to perform than that of keeping up the fire. To apply this power to the purpose of raising water for draining a mine, suppose a common sucking-pump placed in the pit to lift the water fifty yards high. If the pump is $7\frac{1}{2}$ inches bore, the column of water which must be raised when the rod or bucket of the pump is drawn up, will weigh 3060 lbs.; a chain being attached to the upper end of the rod of the pump, and suspended from the extremity of the

long lever or working beam; and at the opposite extremity of the same beam another chain must be attached, to suspend the piston of the steam cylinder, which we have just described.

To give this piston a sufficient power of descent to make it draw up the water in the pump at the opposite end of the beam with celerity, the piston must be 22 inches in diameter; the area or surface of the piston will then be 380 square inches, $22 \times 22 = 484 \times .7854 = 380$. In this case, if each square inch is pressed with a weight of eight pounds, it will balance the weight of the water in the pumps within 20 pounds; for $380 \times 8 = 3040$, instead of 3060: but the pressure on each square inch will be considerably more than eight pounds; for, provided the vacuum was perfect within the cylinder, the pressure of the atmosphere would be $14\frac{1}{2}$ pounds; but the condensation of the steam in the cylinder is so far incomplete, that it leaves steam or vapour within the cylinder of some density. If the steam is cooled by the injection down to 140° , it will be seen by our first table, fourth column, that it will leave the cylinder filled with a vapour of an elastic force equal to 2 lbs. 13 oz. *per* square inch; which force acting beneath the piston, will deduct from the pressure of the atmosphere, and reduce the neat pressure on the piston to 11 lbs. $13\frac{1}{2}$ oz. *per* square inch, as shewn by the last column. The excess of pressure beyond what is necessary to balance the weight of water is 3 lbs. *per* square inch, amounting, on the whole surface of the piston, to $(3 \times 380 =) 1140$ lbs. nearly, a weight which is allowed to overcome the counter-weight which is to draw the piston up again, and the friction of the piston and pump-buckets, and make the engine move with a sufficient velocity, which will be more or less according to the state of the engine. But taking this velocity at 16 strokes *per* minute of six feet length each = 96 feet motion *per* minute, the pump of $7\frac{1}{2}$ inches diameter will raise 192 gallons *per* minute, or 182 hogshheads 13 gallons *per* hour. An engine of these dimensions is but a small one, yet it serves to shew the superiority of Newcomen's over Savery's engine, in principle. Savery's was an engine which really raised water by the force of steam; but Newcomen's raises water entirely by the pressure of the atmosphere, steam being employed merely as the most expeditious method of producing a void, into which the atmospherical pressure may impel the first mover of his machine. The elasticity of the steam is not the first mover. In the example of the engine we have just given to drain the same mine on Savery's plan, he must have employed steam of a pressure of 55 pounds *per* inch, and of a temperature of 325° degrees, to raise a column of water to a height of 125 feet: the condensation of this steam would be so great on coming in contact with water of only 50° degrees, that he would have found it scarcely practicable to have thrown up any considerable quantity.

We see also the great superiority of this new machine. There is no need of steam of great and dangerous elasticity, as it operates by means of very moderate heats, and consequently with much smaller quantities of fuel; and there are no other bounds to the power of this machine, than the strength of the materials of which it is composed. How deep soever a mine may be, a cylinder may be employed of such dimensions, that the pressure of the air on its piston may exceed in any degree the weight of the column of water to be raised; and lastly, this form of the machine renders it applicable to almost every mechanical purpose, because a skilful mechanic can readily find a method of converting the reciprocating motion of the working beam into a motion of any kind which may suit his purpose. Savery's engine could

not admit of such an immediate application, and was restricted to raising of water.

Invention of Newcomen's Engine.—Respecting the invention of this engine, it was less a matter of original discovery, than of a combination of the inventions of others, *viz.* of Savery's invention of the means of producing a vacuum by the condensation of steam, with Otto Guericke's exhausted cylinder.

Savery made claim to the invention, and in consequence of the claim he made to the mode of condensation, as being a part of his patent, he was admitted by Newcomen and Cawley to an association with them in the patent which was granted in 1705, but it does not appear that they made any perfect engine until 1711.

Defaguliers, in his account of the invention, makes no mention of captain Savery being associated; but says "that Thomas Newcomen, ironmonger, and John Cawley, glazier, of Dartmouth, in the county of Southampton (Baptists), made several experiments in private about the year 1710, and in the latter end of the year 1711 made proposals to drain the water of a colliery at Griff, in Warwickshire, where the proprietors employed 500 horses at an expence of 900*l.* a year; but their invention not meeting with the reception they expected, in March following, through the acquaintance of Mr. Potter of Bromsgrove, in Worcestershire, they bargained to draw water for Mr. Back of Wolverhampton; where, after a great many laborious attempts, they did make the engine work: but not being either philosophers to understand the reason, or mathematicians enough to calculate the powers and proportion of the parts, they very luckily, by accident, found what they sought for.

"They were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the pump-valves, clacks, and buckets, whereas they had but an imperfect notion of them before. One thing is very remarkable; as they at first were working, they were surprised to see the engine go several strokes, and very quick together, when, after a search, they found a hole in the piston, which let the cold water in to condense the steam in the inside of the cylinder, whereas before they had always done it on the outside. They used before to work with a buoy in the cylinder, inclosed in a pipe, which buoy rose when the steam was strong and opened the injection, and made a stroke; thereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy, Humphrey Potter, who attended the engine, added (what he called *scoggan*) a catch, that the beam always opened, and then it would go 15 or 16 strokes a minute. But this being perplexed with catches and strings, Mr. Henry Beighton, in an engine he had built at Newcastle-upon-Tyne, in 1718, took them all away, but the beam itself, and supplied them in a much better manner." Since that time no very material alterations have been made in this species of engine, except the addition of the crank to make it turn mills.

The French authors have claimed this engine also as the invention of their countryman Papin, but without any reason: Papin had gained a knowledge of the expansive force of steam in his digester, and he invented the mode of working the pistons and cylinders by a vacuum and the pressure of the atmosphere; but he was not the first inventor of either of these, Otto Guericke and the marquis of Worcester having discovered the same things long before him; and further, he had no pretensions to claim Savery's discovery of the condensation of steam, upon which the engine of Newcomen depends.

Papin's Air Cylinder Engine.—Papin's invention of the cylinders

linders is by no means void of merit, we shall therefore briefly describe it, and our readers will see how far it could have assisted Newcomen, supposing him fully informed of it.

The first engine was for the purpose of transmitting the action of a water-wheel to a great distance, by means of air in pipes. Papin proposed this principle enigmatically, as a new way of raising water, to the Royal Society in 1685; and after many solutions had been given by the English academicians, he shewed the real application and use of it, to raise water out of a mine by the power of a river at a considerable distance.

For this purpose, a water-wheel was to be placed in the river, to work the pistons of two large cylinders of pumps, from the lower ends of each of which small pipes were conducted down into the mine, to convey the air into small chests or receivers, which were each furnished with a suction-pipe and a forcing-pipe, and valves to prevent the descent of the water. By the motion of the pistons of the pumps, the air was to be alternately rarefied and compressed in these chambers; and thus he intended to draw water into the receptacles through the suction-pipes, and then force it up through the forcing-pipe; but he forgot that, in this method, the elasticity of the air he employed would wholly defeat his end; for when the piston of the pump was depressed, it would not compress the quantity of air contained in a long pipe sufficiently to produce any sensible condensation to force or raise water out of the receiver; nor, on the other hand, could a sufficient rarefaction of the air be produced by the ascent of the piston to obtain any efficient suction in the receivers.

Papin afterwards made some alterations to obviate the objections which were urged by Dr. Hooke and other English philosophers, and in 1688 he published another machine in the *Acta Eruditorum*, which is more complete, and is a most valuable invention for conveying the power of machines to a distance. Within these few years it has been employed in this country, though secretly, for a very important purpose.

In this method, the two pumps, which are worked by alternate cranks on the axle of the water-wheel, are provided with valves similar to those of an air-pump, and they draw air alternately from the conveyance-pipe which leads to the mine, so as to make a vacuum in the pipe. At the mine are placed two cylinders, with pistons fitted into them; and a rope, which is fastened to each of the pistons, is wrapped several times round an axle or horizontal shaft, which is extended over both cylinders, and is put in motion by their pistons.

Upon the middle of this axle is a large wheel, for the reception of a cord, which descends into the mine, and has at each end a bucket; therefore, by turning the axle first one way round, and then the other, the two buckets are alternately drawn up or lowered down in the mine, to draw either water or ore. The ropes from the piston of the cylinders are wrapped round the axle in opposite directions; and when one piston is pressed down, it will draw the rope and turn the axle, which winding up, the other rope will draw up the piston of the other cylinder. A single conveyance-pipe leads from both the air-pumps at the water-wheel; but when the pipe arrives in the mine it divides into two branches, one for each cylinder; and at the intersection of these branches a double-passaged cock is placed, which will admit the air from either of the cylinders into the conveyance-pipe which leads to the air-pumps, or it will admit the atmospheric air into the cylinders; and these passages are opened alternately by the cock, so that whilst the air from one cylinder is drawing off through the conveyance-pipe by the air-pumps, the atmospheric air shall have free entrance to the other cylinder.

The consequence will be, that by the continual suction of the air-pumps a vacuum will be found under one piston, and the pressure of the atmosphere will act to press it down in its cylinder; and by the rope which is attached to it and wound round the axle of the wheel, its descent will cause the axle and wheel to turn round and draw up the cord which passes over the wheel at one side, so as to raise up one bucket in the mine and lower down the other; but during the descent of this piston, the other piston is freely at liberty to be drawn up in its cylinder, because the cock admits the atmospheric air into the same. When the piston under which the vacuum has been made is pressed down to the bottom of its cylinder, the other piston will be drawn up to the top of its cylinder, by its rope winding upon the axle. In this state the cock is turned the other way, and will then draw off the air from the cylinder in which the piston is at the top, and admit fresh air into the cylinder in which the piston is at the bottom. This will cause the axle and wheel to turn round in an opposite direction to what it did before, and draw up the opposite bucket from the mine.

In this way a constant reciprocation of the motion of the axle is kept up, and the power of the water-wheel is transmitted simply by the conveyance-pipe to any required distance, where, by using a larger or smaller cylinder, it may be made to act with any required force. The inventor proposed this method to be used to convey the power of the water-wheels in the Seine to work pumps at Versailles, instead of the cumbersome machinery employed at Marly for conveying the motion; and it is rather surprising that so simple and advantageous a method should have remained so long neglected and unknown, that even now, when its effects are publicly exhibited, the means are not known. The only improvement upon the method of Papin, which it is necessary to put in practice, is to have a receiver or air-chamber near the cylinders, to be kept exhausted by the pumps; and this being of sufficient capacity the air will rush into it, and be taken away from beneath the piston the instant the cock is opened; whereas without it, it would be drawn off more slowly by the pumps. If the conveyance-pipe is made of large dimensions, it will effect the same end most completely.

Description of the Atmospheric Engine.—Our readers being now acquainted with the principle of Newcomen's engine, we shall proceed to describe it in the state to which it was brought by Mr. Beighton, and which for more than half a century was the standard engine for raising water from mines. See the perspective view in *Plate II. fig. 1.* which represents the engine complete, the front wall of the house being supposed to be removed to shew the interior.

A, the fire-place under the boiler for raising the steam, and the ash-hole below it.

B, the boiler, made of iron plates: it is filled with water about three feet above the bottom.

C, the steam-pipe, through which the steam passes from the boiler into the receiver.

D, the receiver, a close iron vessel or box, in which is the regulator or steam-cock, which opens and shuts the hole of communication with the cylinder at each stroke.

E is the communication-pipe, between the receiver and the cylinder; it rises five or six inches up in the inside of the cylinder above the bottom, to prevent the injected water from descending into the receiver.

F, the cylinder of cast-iron, about ten feet long, bored smooth in the inside; it has a broad flange in the middle, on the outside, by which it is supported when hung between the cylinder-beams, which extend across the house, and are let into the side-wall.

G, the piston, made to fit the cylinder exactly, but with liberty to slide up and down; it has a flanch rising four or five inches upon its upper surface, between which and the side of the cylinder a quantity of junk or oakum is stuffed, and kept down by weights, to prevent the entrance of air or water, and the escape of steam.

H, the chain and piston-shank, by which it is connected to the working beam by an arc of a circle.

I I, the working beam or lever, working on its centre, in the manner of a scale-beam; it is made of two or more large logs of timber, bent together at each end, and kept at the distance of eight or nine inches from each other in the middle by the gudgeon or centre, as represented in the plate. The arch-heads **l, l**, at the ends of the beam, are for giving a perpendicular direction to the chains of the piston and pump-rods, which are suspended at the opposite ends.

K, the pump-rod, which works in the great sucking-pump **L**, and draws the water from the bottom of the mine to the surface.

M, a cistern, into which the water drawn out of the pit is conducted by a trough, so as to keep it always full, and the superfluous water is carried off by another trough.

N, the jack-head pump, which is a smaller sucking-pump, wrought by a small lever or working beam, by means of a chain connected to the great beam or lever near the arch **g**, at the inner end; and the rod of the pump **N** is suspended by a chain at the outer end. This pump commonly stands near the corner of the front of the house, and raises a column of water up to the cistern **O**, into which it is conducted by a trough.

O, the jack-head cistern, for supplying the injection; it is always kept full by the pump **N**, and is fixed so high above the cylinder bottom, as to give the jet of injection a sufficient velocity into the cylinder when the cock is opened. This cistern has a waste-pipe on the opposite side for conveying away the superfluous water.

P P, the injection-pipe, of two or three inches diameter, which descends from the cistern, **O**, to the injection-cock **r**, after passing which it turns up in a curve at the lower end, and enters the cylinder bottom. It has a thin plate of iron screwed upon the end **d**, which is within the cylinder, with three or four ajutage holes in it, to cause the jet of cold water from the jack-head cistern to fly up in as many streams against the under surface of the piston, and condense the steam contained in the cylinder each stroke, when the injection-cock is open.

e, a valve upon the upper end of the injection-pipe, which is shut, to prevent waste of water by leakage when the engine stands still; but before the engine is set to work, this valve must be lifted up, and kept open by a string.

f, a small pipe, which branches off from the injection-pipe, and has a cock to supply the piston with a little water to keep it air-tight.

Q, the working plug, suspended by a chain to the small arch, **g**, of the working beam. It is usually a heavy piece of timber, with a slit vertically down its middle, and holes bored horizontally through it to receive pins, for the purpose of opening and shutting the injection and steam-cocks, as it ascends and descends by the motion of the working beam.

h, the handle of the steam-cock or regulator. It is fixed to the regulator by a spindle, which comes up through the top of the receiver. The regulator itself is a sectorial plate of brass, shaped like a fan, which is moved horizontally by the handle **h**, and opens or shuts the communication at the lower end of the pipe **E**, within the receiver. It is represented separately in the plate by *fig. 2*.

i i, the spanner, which is a long rod or bar of iron, for communicating motion to the handle of the regulator, to which it is fixed by means of a slit in the latter, and some pins put through to fasten it.

k l, the vibrating lever, called the tumbling-bob, or the **Y**, having the weight **k** at one end, and the two forked legs at the other end, like the letter **Y** turned. It is fixed to an horizontal axis, moveable about its centre pins, or pivots, **m, n**, and is put in motion by means of the two shanks **o, p**, fixed to the same axis, which are alternately raised and depressed by means of two pins in the working plug, and the bob or weight at the top of the **Y** is thrown backwards and forwards; one pin on the outside, depressing the shank **o**, throws the loaded end, **k**, of the **Y** from the cylinder into the position represented in the plate, and causes the leg, **l**, of the fork of the **Y** to strike against the end of the spanner, which forcing back the handle of the regulator or steam-cock opens the communication, and permits the steam to fly into the cylinder. The piston immediately rises by the weight of the pump-rod, on the admission of the steam: the motion of the working beam, **I I**, also raises the working plug; and another pin, which goes through the slit, raises the shank, **p**, of the axis, which throws the end, **k**, of the **Y** towards the cylinder, and the leg of the fork, striking the end of the spanner, forces it forwards, and shuts the regulator or steam-cock.

qr is the lever for opening and shutting the injection-cock, called the **F**. It has a rack or toothed sector fixed upon its axis, which takes the teeth of a pinion, fixed on the top of the plug or key of the injection-cock. When the working plug has ascended nearly to its greatest height, and shut the regulator, as above described, a pin catches the end, **q**, of the **F**, and raises it up, which opens the injection-cock, and admits a jet of cold water to fly into the cylinder, and condensing the steam, makes a vacuum within. Then the pressure of the atmosphere, forcing down the piston into the cylinder, causes the plug-frame to descend, and another pin fixed in it catches the end of the lever, **q**, in its descent, and by pressing it down shuts the injection-cock; at the same time the regulator is opened to admit steam, and so on alternately; that when the regulator is shut, the injection-cock shall be open, and when the former is open, the latter shall be shut.

R, the eduction-pipe, to convey away the water which is injected into the cylinder at each stroke; its upper end is even with the cylinder bottom, and its lower end has a lid or cover, moveable on a hinge, which serves as a valve to let out the injected water, and shuts close each stroke of the engine, to prevent the water being forced up again when the vacuum is made.

S, the hot-well, which is a small cistern made of planks, to receive all the waste water from the cylinder, and keep it in reserve for feeding the boiler, to supply the waste occasioned by the continual evaporation of the steam.

T, the feeding-pipe, to supply the boiler with water from the hot-well. It has a cock to let in a large or small quantity of water, as occasion requires, to make up for what is evaporated: it goes nearly down to the boiler bottom, so that the lower end is always immersed in water.

U, two gauge-cocks, in the upper ends of two pipes which descend into the boiler; one is deeper than the other: their use is to try when a proper quantity of water is in the boiler, for upon opening the cocks, if one gives steam and the other water, it is right, because the intended level of the water in the boiler is between the ends of the two. If they both give water there is too much.

W is the man-hole: it is a plate which is screwed over

a hole on the side of the boiler, to allow a passage into it for the convenience of cleaning or repairing.

X, the steam-clack or puppet-valve, which is a brass valve, on the top of the pipe opening into the boiler, to let off the steam when it is too strong. It is loaded with lead at the rate of one pound to an inch square; and when the steam is nearly strong enough to keep it open, it will do for the working of the engine.

s, the snifting-valve, by which, at every ascent of the piston, the air is discharged from the cylinder which was admitted with the injection, and would otherwise obstruct the due operation of the engine.

tt, the cylinder beams, which are strong girders going through the house, for supporting or rather keeping down the cylinder.

v, the cylinder cup of lead surrounding the top of the cylinder, to prevent the water upon the piston from flashing over when it rises too high.

w, the waste-pipe, which conducts the superfluous water from the top of the cylinder to the hot-well.

xx, iron bars, called the catch-pins, fixed horizontally through each arch-head to strike the floor, and prevent the beam descending too low, in case the chains at either end should break, or if the engine makes too long a stroke.

yy, two strong wooden springs, to weaken the blow given by the catch-pins, when the stroke is too long.

zz, two friction-wheels or sectors, on which the gudgeons, or centres of the great beam, are supported; they are the third or fourth part of a circle, and move a little each way as the beam vibrates.

Their use is to diminish the friction of the axis, which being necessarily very large for so heavy a lever, would otherwise be very great.

Operation of the Atmospheric Engine.—When this engine is to be set to work, the boiler must be filled about two or three feet deep with water, and a large fire made under it; and when the steam is heated to be of sufficient strength to exert a pressure of about one pound beneath each square inch of the safety-valve, it will lift up the valve and escape. The water in the boiler being supposed to be in a strong state of ebullition, and the steam issuing by the safety-valve, we will consider the machine in a state of rest, having both the steam-cock and injection-cock shut. The resting position or attitude of the machine is such as appears in the drawing, the pump-rods, K, preponderating by their weight; and the great piston being drawn to the top of the cylinder.

The man who attends the engine depresses the handle p, so as to throw the tumbling-bob into the position of the figure; and the leg of the fork thrusting back the spanner ii, opens the regulators or steam-cock, when the steam from the boiler immediately rushes in, and flying all over the cylinder, will mix with the air: much will be condensed by the cold surface of the cylinder and piston, and the water produced from it will trickle down the sides, and run off at the eduction-pipe, R, as soon as any quantity is accumulated. This condensation and waste of steam will continue, till the whole cylinder and piston are made as hot as boiling water.

When this happens, the steam will begin to open the snifting-valve s, and issue through the pipe; at first slowly and very cloudy, being mixed with much air, the cloudy appearance of steam being always owing to its mixture with common air. The blast at s will grow stronger by degrees, and more transparent, having already carried off the greatest part of the common air which filled the cylinder. We supposed, at first, that the water was boiling briskly,

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so that the steam was issuing by the safety-valve, which is in the top of the boiler. The opening of the steam-cock puts an end to this at once, because the cold cylinder draws off the steam from the boiler with astonishing rapidity, until it becomes heated so as not to condense.

When the manager of the engine perceives that not only the blast at the snifting-valve is strong and steady, but that the boiler is fully supplied with steam of a proper strength, which appears by the renewal of the discharge at the safety-valve, the engine is ready for starting. He now lifts up the handle o or p, till the tumbling-bob, Y, falls over the perpendicular towards the cylinder, and its leg striking the cross-pin of the spanner, i, draws it forwards, and shuts the steam-regulator; at the same instant he lifts up the handle, q, of the F, which opens the injection-cock. The pressure of the column of water in the injection-pipe, P, immediately forces some water through the spout d, by the jets.

The cold water coming in contact with some of the pure vapour, which now fills the cylinder, condenses it, and thus makes a partial void, into which the more distant steam immediately expands; and by this very expansion its capacity for heat is increased; or, in other words, as it grows cold, it abstracts the heat more powerfully from the steam situated immediately beyond it.

In this expansion and refrigeration the steam is itself partly condensed or converted into water, and leaves a void, into which the circumjacent steam immediately expands, and produces the same effect on the steam beyond it: and thus it happens, that the abstraction of a small quantity of heat from an inconsiderable mass of steam produces a condensation throughout a cylinder which is very extensive.

What remains in the cylinder no longer balances the atmospheric pressure on the surface of the water in the injection-cistern, and, therefore, the water spouts rapidly through the holes d, by the joint action of the column P, and the unbalanced pressure of the atmosphere; at the same time the snifting-valve s, and the eduction-valve R, are shut by the external pressure of the atmosphere, and prevent the entrance of air or water into the cylinder. The velocity of the injection-water must therefore rapidly increase, and the jets dash against the bottom of the piston, and be scattered through the whole capacity of the cylinder. In a very short space of time therefore, the condensation of the steam becomes universal, and the elasticity of what remains is very small. The whole pressure of the atmosphere, therefore, being exerted on the upper surface of the piston, while there is hardly any on its under side, if the load on the outer end of the working-beam is inferior to this pressure, it must yield to it. The piston G must descend, and the pump-piston k must ascend, bringing along with it the water of the mine; but the motion does not begin at the instant the injection is made.

The piston was kept at top by the preponderancy of the outer end of the working beam and the load of water in the pumps, and it must remain there, till the difference between the elasticity of the steam below it, and the pressure of the atmosphere, exceed this preponderancy. There must, therefore, be a small space of time between the beginning of the condensation and the beginning of the motion: this is very small, not exceeding the third or fourth part of a second; but it may be very distinctly observed by an attentive spectator, who may perceive, that the instant the injection-cock is opened, if the cylinder has the slightest yielding in its suspension, it will heave upwards a little by the pressure of the air on the bottom. Its own weight is not at all

H

equal to this pressure; and instead of its being necessary to support it by a strong floor, it must be kept down by large beams, loaded at the end with heavy walls. This heaving of the cylinder shews the instantaneous commencement of the condensation; and it is not till after this has passed, that the piston is seen to start, and begins to descend.

The motion must continue till the great piston reaches the bottom of the cylinder, because it is not like the motion which would take place in a cylinder of air rarefied to the same degree. In this latter case, the impelling force would be continually diminished, because the capacity of the cylinder diminishing by the descent of the piston, the air in it would continually become more dense and elastic, until the piston would stop at a certain height, where the elasticity of the included air, together with the load at K, would balance the atmospheric pressure on the piston. But when the contents of the cylinder are pure vapour, and the continued stream of injected cold water keeps down its temperature to the same pitch as at the beginning, the elasticity of the remaining steam can never increase by the descent of the piston, nor exceed what corresponds to the temperature, according to our table. The impelling or accelerating force, therefore, remains the same; and the descent of the piston will be accelerated almost uniformly, unless there is an increase of resistance, arising from the nature of the work performed by the other end of the beam. And it may be frequently observed in a good steam-engine, where every part is air-tight, that if the cylinder has been completely purged of common air before the steam-cock is shut, and if none has entered since, the piston will descend to the very bottom of the cylinder. It sometimes happens, by the great pump drawing air, or some part of the communication-chains giving way, that the piston descends with such violence as to beat out the bottom of the cylinder with the blow, and it is to prevent this accident that the catch-pins are applied at the end of the beam.

When the manager sees the piston as low as he thinks proper, he shuts the injection-cock, by depressing the lever *g*; and at the same time he opens the regulator, by forcing down the handle *o*, which oversets the tumbling-bob, and its leg catching the cross-pin of the spanner, *i*, opens the regulator.

The steam has been accumulating above the water in the boiler during the whole time of the piston's descent. The moment, therefore, that the steam-cock is opened, the steam, having an elasticity of rather more than one pound *per* square inch greater than that of the air, rushes into the cylinder, when it immediately blows open the snifting-valves, and admits the water which had come in by the former injection, and what arose from the condensed steam, to descend by its own weight through the eduction-pipe *S*, and open the valve to run out into the hot-well *R*.

This water is nearly boiling-hot, or at least its surface; for while lying in the bottom of the cylinder, it will condense steam till it acquires this temperature, and therefore cannot run down till it will condense no more. There is a cause of some waste of steam at its first admission, in order to heat the inside of the cylinder, and the injected water, to the boiling temperature; but the space being small, and the whole being already very warm, it is very soon done; and when things are properly constructed, little more is wanted than what will warm the cylinder; for the eduction-pipe is made of large dimensions, and receives some of the injection-water even during the descent of the piston, and this portion will be removed out of the way of the steam.

The first effect of the entering steam is of great service; it drives out of the cylinder the vapour which it finds there.

This is seldom pure steam, or watery vapour, because all water contains a quantity of air in a state of chemical union; but the union is only feeble, and a boiling heat is sufficient for disengaging the greatest part of it, by increasing its elasticity. It may also be disengaged by simply removing the external pressure of the atmosphere. This is clearly seen when we expose a glass of water in an exhausted receiver. Therefore the small space below the piston contains watery vapour, mixed with all the air which had been disengaged from the water in the boiler by ebullition, and all that was separated from the injection-water by the diminution of external pressure, in addition to any which may enter by leakage.

Let us now consider the state of the piston, when setting out on its return; as it is evident that it will start, or begin to rise by the counter-weight, the moment the steam-cock is opened; for at that instant the excess of atmospheric pressure, by which it was kept down in opposition to the preponderancy of the outer end of the beam, is diminished. At the first instant of the return of the pump-rods, they draw up the piston with great violence, all the weight of the water in the pumps acting in addition to the counter-weight; but the falling of the lower valves in the pumps, after an inch or two of motion, arrests the further descent of the water, and bears the weight of the column of water; and after this the piston will rise gradually by the action of the counter-weight.

The action of the counter-weight is very different in the two motions of the engine; for while the engine is making a working stroke, it is lifting not only the column of water in the pump, but the absolute weight of the bucket-rods also; and while the pump-rods are descending, there is a diminution of the counter-weight, by the whole weight lost by the immersion of the rod in water. The wooden rods which are generally used being soaked in water, and joined by iron straps, are heavier, and but a little heavier, than water, and they are generally about one-third of the bulk of the water in the pumps.

By this counter-weight the piston is drawn upwards; and it would even rise, although the steam which is admitted was not quite so elastic as common air.

Suppose the mercury in the barometer to stand at 30 inches, and that the preponderancy at the outer end of the beam was equal to $\frac{1}{3}$ th of the pressure of the air on the piston, the piston would not rise until the elasticity of the steam was equal to $30 - \frac{1}{3}$, that is, to 26 $\frac{2}{3}$ inches nearly; but if the steam was just equal to this quantity, the piston would rise as fast as the steam of that density could be supplied to the cylinder through the steam-pipe; and on this supposition, the velocity of the ascent would depend on the velocity of that supply. But this is not the case in practice, because the steam must be stronger than the air, in order to blow out and discharge the air; it will therefore enter the cylinder without any effort on the piston to draw or suck it in. At the same time, the counter-weight must not be so great as to draw up the piston with that force which will cause a suction within the cylinder greater than the steam-pipe can supply, or it would diminish the pressure of the steam within the cylinder lower than the atmosphere, and prevent it from snifting or blowing out the air.

In filling the cylinder with steam, it will require a much more copious supply of steam than merely to fill up the space left by the ascent of the piston; for as the descent of the piston was only in consequence of the vacuum occasioned by the interior of the cylinder being sufficiently cooled to condense the steam, this cooled surface must be again presented to the steam during the rise of the

piston, and must condense steam a second time. The piston cannot rise another inch, till that part of the cylinder which the piston has already quitted has been warmed up to the boiling point, and much steam must be expended in this warming; for the inner surface of the cylinder must not only be raised to the heat of boiling water while the piston rises, but must also be made perfectly dry; and the film of water left on it by the ascending piston must be completely evaporated, otherwise it will continue to condense steam.

On this account, although the counter-weight is not necessary to suck in the steam, the moving force during the ascent of the piston must be considered as resulting chiefly, if not solely, from the preponderating weight of the great pump-rods; and this force is expended partly in returning the steam-piston to the top of the cylinder, where it may be again pressed down by the air, and make another working stroke by raising the pump-rods; and partly in returning the pump-buckets into their places at the bottom of their respective working barrels, in order that they may also make another working stroke. This latter requires force independent of the friction and inertia of the moving parts; for each bucket must be pushed down through the water in the barrel, which must lift up and rise through the valves in the bucket with a velocity proportioned to the velocity of the bucket, in the same degree as the area of the pump-barrel is proportioned to the opening of the valves through which the water must pass.

From this general consideration of the ascent of the piston, we may see that the motion differs greatly from the descent; it can hardly be supposed to accelerate, even if the steam was supplied to the cylinder in ever such quantity: for the resistance to the descent of the pump-bucket is the same with the weight of the column of water, which would cause water to flow through the valves of the buckets with the velocity with which it really rises through them, and this resistance must therefore increase as the square of that velocity increases; that is, as the square of the velocity with which the bucket descends. Independent of the force of friction, and the weight of the valves, the velocity of descent through the water must soon become a maximum, and the motion will become uniform. Accordingly, any one who observes with attention the working of a steam-engine, will see that the rise of the piston and descent of the pump-rods are extremely uniform, whereas the working stroke is very sensibly accelerated.

These two motions complete the period of the operation, and the whole may be repeated by shutting the regulator, and opening the injection-cock whenever the piston has attained the proper height. For the first two or three strokes, the opening and shutting of the cocks are performed by the attendant; but when he has thus ascertained that all parts are in order, he puts pins into the holes of the plug-frame, and the motion of the engine will then actuate its own machinery, and perform its reciprocations with greater regularity than can be done by hand.

Particulars of different Parts of the Atmospheric Engine.—We shall now pay some attention to the construction of the parts of this engine, and notice some further particulars.

The furnace or fire-place should not have the grate-bars so close as to prevent the free admission of air, nor so open as to let the coals fall through. About two inches are sufficient for the distance betwixt the bars. The height from the bars to the bottom of the boiler in the centre should not be more than two feet, and the concavity or rise of the bottom in the centre about one foot.

The size of the furnace depends upon the size of the boiler; but in every case the ash-hole ought to be capacious,

to admit the air. If the flame is conducted in a flue or chimney round the outside of the boiler, or in a pipe round the inside of it, it ought to be gradually diminished from its entrance at the furnace to its egress at the chimney; and the section of the chimney at that place should not exceed the section of the flue or pipe, and should also be somewhat less at the chimney-top.

The boiler or vessel, in which the steam is made by the force of fire, may be formed of iron plates, or copper, or of cast-iron, the bottom being of such materials as can withstand the effects of the fire, and have sufficient strength to retain the elastic force of the steam. It may be considered as consisting of two parts; an upper part, which is exposed to the steam, and an under part, which is exposed to the fire. The form of the latter should be such as to receive the full force of the fire in the most advantageous manner, so that a certain quantity of fuel may have the greatest possible effect in heating and evaporating the water; which is best done by making the sides cylindrical, and the bottom a little concave, and then conducting the flame by an iron flue or pipe round the inside of the boiler, beneath the surface of the water, before it reaches the chimney. For by this means, after the fire in the furnace has heated the water by its effect on the bottom, the flame heats it again by the pipe being wholly included in the water, and having every part of its surface in contact with it; which is preferable to carrying it in a flue or chimney round the outside of the boiler, as a third or a half of the surface of the flame only can be in contact with the boiler, the other being spent upon the brick-work. This cylindric lower part may be less in its diameter than the upper part, and may contain from three to five feet perpendicular height of water in it.

The upper part of the boiler is best made hemispherical for resisting the elasticity of the steam; yet any other form may do, provided it be of sufficient strength for the purpose.

The quick going of the engine depends much upon the capaciousness of the boiler-top; for if it be too small, it requires the steam to be heated to a greater degree to increase its elastic force sufficiently to work the engine, and then the condensation on entering the cylinder will be greater. If the top is so capacious as to contain eight or ten times the quantity of steam used at each stroke, it will require no more fire to preserve its elasticity than is sufficient to keep the water in a proper state of boiling; this, therefore, is a sufficient size for the boiler-top.

It is usual to place a damper, or iron slider, in the chimney, or in the flue leading into the chimney; and this has a chain or lever, by which the attendant can regulate the aperture of the chimney, and consequently the draught of the fire, so as to keep the steam to a great regularity: for it is evident, that when the engine works slowly, it will require less steam and fuel than when working rapidly; and without the damper, the engine would be constantly exposed to an excess or deficiency in the supply of steam. The boiler is, in some engines, placed immediately beneath the cylinder, the same as represented in *Plate III.*; and then the regulator is placed immediately within the boiler, and acts against the under surface of its top, in the same manner as in the first engine of captain Savery, who invented the regulator.

It was a subsequent improvement of Newcomen's engine to remove the boiler from immediately beneath the cylinder to a small shed on the outside of the engine-house; by this means the height of the building is considerably reduced; and as the wall which supports the beam-centre does not require to be carried to so great a height, it is more enabled to withstand the violent shocks to which it is constantly subjected from the working of the engine. Another and

still greater advantage is, that two boilers can be employed; or when the original boiler requires to be repaired or renewed, it can be replaced by erecting another at one side, and carrying another steam-pipe to the steam-box: in this way the working of the engine can be continued without any stoppage; a circumstance of the greatest importance where the water must be constantly kept drained.

In either case, whether the regulator is placed in the boiler itself, or in the steam-box beneath the cylinder, it is constructed in the manner represented in *Plate II. fig. 2*. It is a flat plate of brass, in shape resembling a fan, the upper surface of which applies itself exactly to the whole circumference of the orifice of the steam-pipe, and completely excludes the steam from the cylinder, being moveable round an upright axis *Q*, which is accurately fitted into a conical socket coming through the lid of the steam-box. It can be turned aside by a lever, or handle, on the upper end of this axis, so as to uncover or open the passage. The profile shews that, in the section of this plate, there is a protuberance in the middle. This rests on a strong flat spring, fixed below it, across the mouth of the steam-pipe, which spring presses it strongly towards the steam-pipe, causing it to apply very close, and the protuberance slides along the spring, while the regulator turns to the right or left. Both the handle of the regulator, and the end of the rod or spanner *ii*, *fig. 1*, are pierced with several holes, and a pin is put through them, which unites them by a joint. The motion of the handle of the regulator may be increased or diminished, by choosing for the joint a hole near to the axis or remote from it, and the exact position at which the regulator is to stop on both sides is determined by pins stuck in a horizontal bar, on which the end of the handle rests.

The tumbling-bob of the *Y* has a long leather check-strap fastened to it by the middle, and the two ends of the strap are fastened to the beams above it in such a manner, that the lump may be alternately caught, and held up to the right and left of the perpendicular. By adjusting the length of the two parts of the strap, the *Y* may be stopped in any desired position. The two legs of the fork spread out from each other, and also from the line of the stalk, thus *X*, and they are of such length as to reach the horizontal pin, which crosses the fork or stirrup of the spanner below.

Now, suppose the pin of the spanner hanging perpendicularly beneath the axis, and the stalk of the *Y* also held perpendicularly, carry it a little outward from the cylinder, and then let it go, it will fall farther out of its weight, without affecting the stirrup of the spanner, till the inner leg strikes on the horizontal pin of the stirrup, and then it pushes the pin of the stirrup and the spanner towards the cylinder, and shuts the regulator. It thus sets the regulator in motion with a smart jerk, which is an effectual way of overcoming the cohesion and friction of the regulator against the mouth of the steam-pipe. This push is adjusted to the proper length by the check-strap, which stops the *Y* when it has gone far enough. If we now take hold of the stalk of the *Y*, and move it up to the perpendicular, the width between its claws is such as to permit this motion, and something more, without affecting the stirrup. But when pushed still nearer to the cylinder, it tumbles suddenly towards it by its own weight, and then the other leg of the fork strikes the pin of the stirrup of the spanner in the opposite direction, till the bob is checked by the strap.

Thus, by the motion of the *Y*, the regulator is open and shut suddenly. This opening and shutting of the steam-passage are executed in the precise moment that is proper, by placing the pins in the plug-beam, which act upon the

handles *c* and *p*, at a proper height. For this reason, it is pierced through with a great number of holes, that the places of these pins may be varied at pleasure: this, and a proper curvature of the handles *c* and *p*, make the adjustment as nice as we please.

In the same manner the motions of the injection-cock are also adjusted to act at the precise moment that is proper for them. The different pins are so placed in the plug-frame, that the steam-cock may be completely shut before the injection-cock is opened. The inherent motion of the machine, or the momentum of its parts, will give a small addition to the ascent of the piston, without expending steam all the while, and by leaving the steam rather less elastic than before, the subsequent descent of the piston is promoted.

The injection-cock is frequently provided with a tumbling-bob, to make it open suddenly. This is an arm extending from the centre of the *F*, or lever *g*, upon which the toothed sector is fixed, and having at its extremity a sufficient weight to open the cock in an instant. When this weight is lifted up to its utmost, the cock is shut, and in this position the weight is detained by a small latch, which is lifted up by a pin in the plug-frame, at the moment when the piston arrives at the top of the cylinder, and thus releasing the weight, it falls all at once, and opens the cock in an instant; but when the piston descends nearly to the bottom, another pin in the plug-frame takes the handle of the sector, and gradually closing the cock, raises the weight till the latch detains it, which happens when the piston is quite at the bottom of its motion.

The injection-cock ought to be opened suddenly; but there is much propriety in closing it gradually: for after the first dash of the cold water against the bottom of the piston, the condensation is nearly complete, and very little more water is necessary, although a continual accession of some is absolutely required for completing the condensation as the capacity of the cylinder diminishes, and the water which is already injected becomes warmed. It is the continuance of this small injection which prevents the vapour in the cylinder becoming more dense as the piston descends.

The effect of the injection in condensing the steam in the cylinder depends upon the height of the reservoir and diameter of the ajutage: if the engine makes a six-foot stroke, then the jack-head cistern should be at least twelve feet perpendicular above the top of the cylinder. The size of the ajutage must depend upon the capacity of the cylinder, as we shall shew by a table; but if the cylinder be very large, it is common to have three or four small holes rather than one large one, in order that the jet may be dispersed the more effectually through the whole capacity of the cylinder. The injection-pipe, or pipe of conduct, should be sufficiently large to supply the injection freely with water. The injection-cistern is the common source from which all the parts of the machine receive their respective supplies of cold water. In the first place, the small branch *f*, which proceeds from the pipe *P*, immediately below the cistern, and is conducted to the top of the cylinder, has a cock at the end, which must be so adjusted, that no more water will run from it than what will keep a constant supply of a few inches of water above the piston to keep it tight. Every time the piston comes to the top of the cylinder it will bring the water along with it, and the surplus of its evaporation and leakage runs off by a waste-pipe *w*. This water necessarily becomes almost boiling-hot, and it was thought proper to employ its overplus for supplying the waste of the boiler. This was accordingly practised for some time; but Mr. Beighton improved this economical thought by supplying the boiler from the eduction-pipe *S*, the water of which

coming from the cylinder, must be still hotter than that above the piston.

This contrivance required attention to several circumstances, which will be easily understood by considering the perspective view. The eduction-pipe comes out of the bottom of the cylinder in an inclined direction, and descends into the hot-well R, where it turns up, and is covered with a valve: in the perspective view may be observed an upright pipe T, which goes through the head of the boiler, and reaches to within a few inches of its bottom. This pipe is called the feeder, and rises about three or four feet above the surface of the water in the boiler: it is open at both ends, and has a horizontal branch from its upper end, communicating with the hot-well R. This communicating branch has a cock, by which its passage may be diminished at pleasure. Now, supposing the steam in the boiler to be very strong, it will cause the boiling water to rise in the feeding-pipe T, and passing along this branch, to rise also in the hot-well, and run over. The height of the surface of water in the hot-well, above the surface of the water in the boiler, is such, that the steam is never strong enough to produce this effect; but, on the contrary, the water in the hot-well will run off by the branch, and go down into the boiler by the feeding pipe, as fast as the opening of the cock will admit. These things being understood, let us suppose a quantity of injected water lying at the bottom of the cylinder, it will run into the eduction-pipe S, and opening the valve in the bottom, will flow into the hot-well. By properly adjusting the cock on the branch of T, the boiler may be supplied with water as fast as the waste in steam-engine requires.

The small quantity that is necessary to supply the boiler might be immediately taken from the cold cistern, without sensibly diminishing the production of steam; for the quantity of heat necessary for raising the sensible heat of cold water to that of the boiling temperature is small, when compared with the quantity of heat that must be combined with it, in order to convert it into steam. The heat expended in boiling off a cubic foot of water, is as much as would bring six cubic feet to a boiling heat from the temperature of 55° ; and little difference can be observed in the performance of such engines as are fed with hot water, and those which have their boilers supplied from a brook. The hot water has, however, the advantage of being free from air; and when an engine must derive all its supplies from pit-water, the water from the eduction-pipe is far preferable to that from the top of the cylinder, because it has been in a measure boiled and distilled.

The interior surface of the cylinder requires to be bored with great exactness; and it must have a sufficient thickness of metal to resist the pressure of the atmosphere, without bending or altering its figure. The piston is made of cast-iron, as nearly as possible to fit the inside of the cylinder, and has all round it, within two inches of the edge, a circular ledge or rim projecting upwards from it, which is both to strengthen the piston, and also to leave a space round between it and the side of the cylinder, to receive the packing or wadding which keeps the piston tight. Mr. Smeaton, who made the best engines on Newcomen's plan, caused the lower surface of the piston to be always planked with elm or beech, about $2\frac{1}{4}$ inches thick. The planking consisted of two broad planks, crossing each other at right angles, and halved into each other at the intersection, so as to come to an equal thickness: the remaining parts or sectors between the arms of this cross were filled up with pieces of the same plank, well tongued and fitted together, and bolted fast to the cast-iron of the piston with one or

two iron rings, let in flat under the lower surface to make it strong: the whole was surrounded with an iron hoop, a quarter of an inch less than the internal diameter of the cylinder. In this case, the cast-iron piston was made less than the wood which formed the bottom of the groove, to receive the wadding, whilst the edge of the cast-iron formed the upright side thereof. The wooden bottom was screwed to the iron with a double thickness of flannel and tar, to exclude the air between the iron and the wood. By this means the piston was less liable to conduct heat; and the wood, being placed with the grain radiating in all directions from the centre, was not liable to expand by the wet. The shank of the piston is made with two prongs, to unite it firmly to the piston; and if the engine is large, it has four prongs, to balance it equally; and the shank must also have two or four chains upon the arch-head. But the chains, when more than one is used, must be united in pairs to the ends of a short horizontal link; and from the middle of this the shank must be suspended, by which means the strain will be equally divided between the two chains. When there are four chains, they must be divided into two pairs, with horizontal links, as above; and the middle parts of these two links must be united to the ends of a longer horizontal link, from the middle of which the shank of the piston is hung: and in this way all the four chains will bear equally.

The upper ends of the chains are jointed to the ends of strong iron bars, supported on the ends of the arch-heads; and at the other ends bolted to the top of the beam, by which means they brace the arch-head.

The original method of making the great working beam was to employ a large tree, and to place the gudgeon or fulcrum under the middle of it, with proper bands to fasten it. The framed beam, represented in the view, was made by Mr. Smeaton: the two middle pieces are formed of whole balks, 12 inches square, put together with the gudgeon between them, which is five inches thick, and notched into the beams, to make it keep its place: the ends of the beams are then sprung together, and bolted fast. This being done, another pair of timbers is applied on the outside of the two former, and others on the outside of these, for the largest engines, making ten balks in the whole. When all these are firmly united, several mortises are cut through between the joints, as shewn by the small square marks in the figure; and into these, hard oak wedges are driven, so that they will be half in each beam, and prevent them from slipping or sliding upon each other in the least; and, in this case, the beams act as ties by the longitudinal strength rather than their flexibility. The great beams which suspend the cylinder, and extend across the house, are compounded of several pieces, in the same manner; and the cylinder has a projecting flanch from the middle of it, to bolt it down to the beams.

The pump-rods or spears, K, are made of wood, with iron straps let in and bolted to them at each end, to join them together: they are made of fir, which is very good wood, as it will bear a great strain endways, if the iron straps are well fitted, and can be obtained in very long pieces. When a mine is of a considerable depth, the pumps cannot be made to lift the whole at once; but the pit must be divided into two, three, or four lifts, and as many different pumps employed; each lifting the water into a cistern, for the supply of that which is above it. Fifty yards are as much as is proper for each lift, but in some very deep mines they are obliged to make them more. It is very difficult, in these cases, to make all the pipes sufficiently strong to bear the pressure of the water, particularly the shock which takes

place when the whole column of water falls upon the valves in shutting: the blow which they then make is like the stroke of a forge-hammer, and soon beats every thing to pieces. The only effectual remedy is the addition of an air-vessel at the side of the pump; but in general the miner makes a hole in the suction-pipe of the pump, just below the clack, and fixes in a cock, with a small valve opening outwards: through this they admit a certain quantity of air every time the pump draws, and this air, mixing with the water in the barrel, condenses, when the valves shut suddenly, and by its elasticity eases the violence of the shock. When the mine is pumped almost dry, the engine will draw a little air at every stroke, at the bottom of the pipes; and this answers the same purpose. See a description of a new pump for mining in our article PUMP.

Rules for determining the Proportions of Atmospheric Engines.—Mr. Newcomen brought forward his engine at a time when almost all the valuable mines in England were coming to a stand for want of more powerful or cheaper machines than were then known; and in consequence, in a few years his invention was put in practice at almost all the mines then existing; and new ones were opened in situations where it would have been impossible to have done it before. The first perfect engine which they erected at Griff, in Warwickshire, had only a 22-inch cylinder, and it was many years before any were made so large as 36: those which we now call small engines, were so much more powerful than any former means of draining water, that they were amply sufficient, until the mines, by growing deeper, required more power. The most obvious means of increasing the force was to change the cylinder for a larger one, and this was most frequently done one or more times; and then, when the beam and other parts would bear no greater strain, a new and larger engine was erected. In this manner they proceeded for many years, until, by gradual increase, the cylinders for common use had reached the enormous powers of 50, 60, and 72 inches diameter.

When it became impracticable to extend them much larger, engineers began to consider the means of improving their performance without increasing their dimensions: also, the consumption of fuel in these large engines was so serious an expense, as to balance the profits of many mines.

At first the fuel was not considered as an object, because the steam-engine, on the whole, was found so much cheaper than any other means of draining water. The best engineers were those who made engines which would fulfil the task assigned to them, and, in comparison to their dimensions and expense of erection, would draw the most water, and be the most certain in the continuance of their operation. We have no accounts of the quantity of fuel consumed by any of those early engines, in proportion to the water which they raised to any given height; but the rules by which they apportioned their cylinders to the work to be performed have been preserved.

Defaguliers tells us, that Mr. Newcomen's way of finding the power of his engine, was to square the diameter of the cylinder in inches, and cut off the last figure, and then call it long hundred weights; and writing a cypher on the right hand, he called the number on that side odd pounds: this he reckoned tolerably exact at a mean, or rather when the barometer was at 30 inches, and the air heavy. The effect of cutting off the last figure from the square of the diameter, is to divide the number of superficial circular inches on the piston's surface into portions of 10 circular inches each; and as the pressure on each of these portions is estimated at a long hundred weight, or 120 lbs., the pressure will be $120 \div 10 = 12$ lbs. *per* circular inch, or 15.3 lbs. *per* square

inch: this, however, must be considered as the full pressure of the atmosphere, if the vacuum was perfect. But to compensate for imperfection, Newcomen allowed between one-third and one-fourth part, and also for what is lost in the friction of the several parts, and for accidents. If, instead of the long hundred of 120 lbs., Newcomen had taken the common hundred of 112 lbs., he would have had $112 \div 10 = 11.2$ lbs. *per* circular inch, or $14\frac{1}{4}$ lbs. *per* square inch, which is still nearer the medium pressure of the atmosphere.

Defaguliers says this rule will agree pretty well with the work at Griff engine, there being lifted at every stroke between two-thirds and three-fourths of the weight of the atmospherical column pressing on the piston; *i. e.* between 10 and $11\frac{1}{4}$ lbs. on each square inch. To give the estimation in round numbers, the diameter of the cylinder of Griff engine will be = 22 inches; this squared is 484; cut off the last figure, and we have 48 cwt. 40 lbs. for the pressure of the atmosphere. The column of water in the pumps weighs about $27\frac{1}{2}$ cwt., to which adding the weight of 73 yards of iron rods, equal about 9 cwt., the weight lifted at the end of the beam would be $36\frac{1}{2}$ cwt., from which we must subtract about 4 cwt. for the piston, and the other weight at that end of the beam, reducing the load to $32\frac{1}{2}$ cwt.; so that the weight of the atmosphere being 48 cwt. 40 lbs. raises a weight of $32\frac{1}{2}$ cwt. with a velocity of six feet in two seconds, considering only the descending stroke of the piston. This requires an effective pressure on the piston of nearly 11 lbs. *per* square inch, including friction and counter-weight; but to balance the weight of the water in the pump, demands a pressure of only 8 lbs. *per* square inch of the piston.

In calculating the powers of the steam-engine, it has been a common mistake with engineers to take into the account no other circumstances than the diameter of the cylinder, and the perpendicular height and diameter of the pumps; from which they calculate only what burthen is laid upon each square inch of the cylinder or piston area, supposing the piston to be at rest, but without paying any regard to the velocity of the engine's motions under such burthen, or the number of strokes *per* minute. Without taking these particulars into the account, it is impossible to calculate the quantity of water raised to a given height, which is the only means of obtaining the exact power or acting force of an engine: it would be like attempting to measure the contents of a solid body by only two dimensions. Steam-engines have at different times been calculated to carry a load varying from 5 lbs. to upwards of 10 lbs. to the square inch; but when working with the light pressure of 5 lbs. to the inch, they are expected to go with double the velocity; that is, the piston to move through double the space in the same time that it would with a pressure of 10 lbs. In this case the same quantity of water would be raised to a given height in the same space of time. In the steam-engine, as well as in other machines, there is a maximum, which cannot be exceeded without applying some new principle; and though by bad workmanship an engine may fall short of what it should do, the best workmanship can only produce a certain effect.

In estimating the power or effect of engines in this manner by the pounds *per* inch in the area of the piston, it must be considered as the clear product of the engine in the column of water it will raise, abstracted of all deductions for friction, counter-weight, &c. For, by attending to the different lifts of pumps in the engine-shaft of a coal or a copper mine, we find that we must, beside the altitudes and the diameters, take into the account the friction of the buckets, and of the water on the sides of the pumps; the

opening of strong double-leathered valves, together with the stones and gravel that enter at the foot of the pump; the inertia of the pump-rods, the chains, the massive lever placed between the cylinder and the pumps, all to be overcome by the pressure on the piston, in addition to the 7 or 8 lbs. *per* square inch. These additions to the power required for the mere raising of the water are so considerable, as to be at least equal to half what is required for the work performed: this will raise the real acting pressure of the atmosphere to $10\frac{1}{2}$ or 12 lbs. *per* square inch. When this is the case, the vapour which remains in the cylinder must be equal in pressure to $4\frac{1}{2}$ or 3 lbs. *per* square inch; and this, by our first table of expansion, will indicate a temperature of from 155° to 142° of Fahrenheit.

In general, the water in the hot-well indicates a lower temperature than this; but although we have but little information concerning the state of the vacuum in the atmospheric engines, when working in their usual state, it must be considerably more perfect than has been suggested by the idea of a pressure of 8 lbs. *per* inch: for an engine carrying a load of $7\frac{1}{2}$ lbs. on the square inch of the piston, together with the friction and inertia, even in large engines, cannot be less

than $11\frac{1}{2}$ lbs. on the inch. Mr. Hornblower informs us that he tried the vacuum of several engines in the county of Cornwall; and in one, which was reckoned the least, the vacuum in the cylinder brought the barometer-gauge to 23, and sometimes 24 inches, instead of 30 inches, at which it would have stood if the vacuum was perfect. If we take the extreme of these observations, it will be 11.6 lbs. on each square inch.

Mr. Henry Beighton seems to have been the first who reduced the steam-engine to any degree of certainty in its operations, and laid down the rules for calculating its powers. Beighton was a mathematician as well as an engineer, and conducted the *Ladies Diary* from 1714 to 1744. For several years he lived at Griff, and had constant opportunities of trying experiments on engines.

We have before noticed his invention of the working-gear, or mechanism, by which the regulator and steam-cock are alternately opened and shut. In 1717, Mr. Beighton published the following table of the necessary proportions of the cylinders of engines to the pumps, when drawing water at different depths, from 15 to 100 yards, in different quantities, from 48 to 480 hogheads *per* hour.

Pumps.							Cylinders.												
Diameter of the Bore	Will hold in a Yard.	Will draw by a Six-foot Stroke.	Weight in one Yard.	At fifteen Strokes in a Minute.	Sixty-three Gallons to a Hoghead.	In one Hour.	The Depth from which Water is to be drawn.												
							Yards.												
In.	Gallons	Gallons.	Lbs.	Gallons.	H. G.	H. G.	15	20	25	30	35	40	45	50	60	70	80	90	100
12	14.4	28.8	146.	462.	7.21	440.	18 $\frac{1}{2}$	21 $\frac{3}{4}$	24	26 $\frac{1}{2}$	28 $\frac{1}{2}$	30 $\frac{1}{2}$	32 $\frac{1}{2}$	34 $\frac{1}{2}$	37 $\frac{1}{2}$	40			
11	12.13	24.	123.5	338.	6.20	369.33	17	19 $\frac{1}{2}$	22	24 $\frac{1}{2}$	26 $\frac{1}{2}$	28	29 $\frac{1}{2}$	31 $\frac{1}{2}$	34 $\frac{1}{2}$	37	39 $\frac{1}{2}$		
10	10.02	20.04	102.	320.	5.5	304.48	15 $\frac{1}{2}$	18	20	22	23 $\frac{1}{2}$	25 $\frac{1}{2}$	27	28 $\frac{1}{2}$	31 $\frac{1}{2}$	33 $\frac{1}{2}$	36	38 $\frac{1}{2}$	40
9	8.12	16.2	82.7	259.8	4.7	247.7	14	16 $\frac{1}{2}$	18	20	21 $\frac{1}{2}$	23	24 $\frac{1}{2}$	27	28	30 $\frac{1}{2}$	33	35	36 $\frac{1}{2}$
8 $\frac{1}{2}$	7.26	14.5	73.9	232.3	3.43	221.15	13 $\frac{1}{2}$	15 $\frac{1}{2}$	17 $\frac{1}{2}$	19	20 $\frac{1}{2}$	21 $\frac{1}{2}$	23	24	26 $\frac{1}{2}$	28 $\frac{1}{2}$	31	32 $\frac{1}{2}$	35 $\frac{1}{2}$
8	6.41	12.8	65.3	205.2	3.16	195.22	12 $\frac{1}{2}$	14 $\frac{1}{2}$	16 $\frac{1}{2}$	18 $\frac{1}{2}$	19	20 $\frac{1}{2}$	21 $\frac{1}{2}$	23	25	27	29	30 $\frac{1}{2}$	32 $\frac{1}{2}$
7 $\frac{1}{2}$	6.01	12.2	61.2	192.3	3.2	182.13	12	14	15 $\frac{1}{2}$	17 $\frac{1}{2}$	18 $\frac{1}{2}$	19 $\frac{1}{2}$	21	22	24 $\frac{1}{2}$	26	28	29 $\frac{1}{2}$	31 $\frac{1}{2}$
7 $\frac{1}{2}$	5.66	11.3	57.6	181.1	2.55	172.30	11	13 $\frac{3}{4}$	15	16 $\frac{1}{2}$	18	19	20	21 $\frac{1}{2}$	23 $\frac{1}{2}$	25	27	28 $\frac{1}{2}$	30 $\frac{1}{2}$
7	4.91	9.8	50.0	157.1	2.31	149.40	10 $\frac{3}{4}$	13	14	15 $\frac{1}{2}$	16 $\frac{1}{2}$	18 $\frac{1}{2}$	19	20 $\frac{1}{2}$	22	24	25 $\frac{1}{2}$	27	28 $\frac{1}{2}$
6 $\frac{1}{2}$	4.23	8.4	43.0	135.3	2.9	128.54	10	12	13	14	15 $\frac{1}{2}$	16 $\frac{1}{2}$	18	19	20	22	23	24 $\frac{1}{2}$	26 $\frac{1}{2}$
6	3.61	7.2	36.7	115.5	1.52	110.1	9 $\frac{1}{2}$	11	12	13	14	15 $\frac{1}{2}$	16	17	19	20 $\frac{1}{2}$	22	23	24 $\frac{1}{2}$
5 $\frac{1}{2}$	3.13	6.2	31.8	99.2	1.36	94.30		10	11	12	13	14	15	15 $\frac{3}{4}$	17	19	20	21	22 $\frac{1}{2}$
5	2.51	5.0	25.5	80.3	1.7	66.61			10	11	11 $\frac{3}{4}$	13	13 $\frac{1}{4}$	14	15 $\frac{1}{2}$	16 $\frac{1}{4}$	18 $\frac{1}{2}$	19 $\frac{1}{4}$	20 $\frac{1}{4}$
4 $\frac{1}{2}$	2.02	2.4	20.5	64.6	1.1	60.60					11	11 $\frac{3}{4}$	12	13 $\frac{1}{2}$	14	15	16	17	18 $\frac{1}{4}$
4	1.6	3.2	16.2	51.2	0.51	48.51					9	10	11	11 $\frac{1}{2}$	12	13 $\frac{1}{2}$	14	15	16

This table is formed on the foundation of the ale-gallon, (containing 282 cubic inches,) which, when filled with pure running water, weighs 10 lbs. 3 oz. avoirdupois; and a superficial inch, on a vacuum, takes in about 14 lbs. 13 oz. of the atmosphere, when the mercury stands at a medium in the barometer.

But allowing for several frictions, and to give a considerable velocity to the engine, experience has taught us to allow but little more than 8 lbs. to an inch in the cylinder's base, that it may make about 16 strokes in a minute, at about six feet each.

An Example for the Use of this Table.—Suppose it was required to draw 150 hogheads *per* hour, at 90 yards deep; in the seventh column, I seek the nearest number, *viz.* 149 hog-

heads, and against it, in the first column, I find a pump of seven-inch bore; then under 90, the depth on the right hand in the same line, I have 27 inches, the diameter of the cylinder fit for that purpose, and so for any other. Henry Beighton.

This estimation of 8 lbs. pressure for each square inch continued for many years to be the rule with engineers who constructed their engines according to this proportion; and if the engines were of a better or worse construction, they would move with a greater or less velocity, because all the excess of pressure which could be obtained above the 8 lbs. was appropriated to overcome the friction and viscosity of the machine; and also to raise the counter-weight: if, therefore, this additional quantity was greater or less, the engine would move quicker, and raise a greater quantity of

water in the same time. Mr. Beighton expected his engine to move 16 strokes *per* minute, of six feet each, or 96 feet of motion *per* minute; but succeeding engineers found them feldom to come up to this, and then began to diminish the burthen to 7 lbs. *per* square inch, and even 6 lbs., in order to obtain a greater velocity of motion.

The celebrated engineer Mr. John Smeaton carried the engine of Newcomen to perhaps as great a degree of perfection as its principle admitted. Having constant occasion to employ large steam-engines in the great works which he executed, he turned his attention to consider the means of improving their effect, and diminishing the consumption of fuel. In calculating the proportions for an engine for the New River Company, in 1767, he considered that the stoppage of the water at every stroke, as well as putting the lever-beam, piston, heavy rods, and chains, from a state of rest into motion, twice at every stroke, was a great loss of power; he therefore determined to work the engine slower, and with larger pumps, and put upon the piston all the load it would bear. To reduce the velocity of the column of water still more, he would place the fulcrum of the beam out of the centre, and make the stroke of the piston nine feet, whilst the pump which lifted 36 feet should work with only a six-foot stroke. This arrangement obliged him to employ a long narrow cylinder, of only 18 inches diameter, and from this he also expected to obtain other advantages; *viz.* that every part of the steam, being nearer the surface of the cylinder, would be more readily condensed; and, in consequence that a less quantity of injection-water would serve the cylinder, which would itself be more heated. Under all these appearances of advantage, he ventured to burden the piston with a pressure of 10.4 lbs. *per* inch. Thus, area of piston (18 inches diameter) 254; weight of the column of water 36 feet in the pumps, 18 inches diameter, 3960 lbs., of which take $\frac{3}{4}$ ths for the difference of the length of stroke, and it gives 2640 lbs. for the weight to be lifted by the piston; and dividing 2640 by 254, the area of the piston, gives 10.4 lbs. pressure *per* inch. "Having once seen a common engine struggle under this burthen, I thought myself (says this ingenious engineer) quite secure under those advantages; but how great was my surprize and mortification, to find that, instead of requiring less injection-water than common, although the injection-pump was calculated to afford as much injection-water as usual, in proportion to the area of the cylinder, with a sufficient overplus to answer all imaginable wants, it was unable to support the engine with injection; and that two men were obliged to assist to raise the injection-water quicker by hand, to keep the engine in motion: at the same time that the cylinder was so cold, I could keep my hand upon any part of it, and bear it for a length of time in the hot-well. By good fortune, the engine performed the work it was appointed to do, as to the raising of water; but the coals by no means answered my calculation. The injection-pump being enlarged, the engine was in a state of doing business, and I tried many smaller experiments, but without any good effect, till I altered the fulcrum of the beam so much, as reduced the load upon the piston from 10 $\frac{1}{2}$ lbs. to 8 $\frac{1}{2}$ lbs. *per* inch. Under this load, though it shortened the stroke at the pump-end, the engine went so much quicker, as not only to raise more water, but consume less coals, took less injection-water, the cylinder become hot, and the injection-water came out at 180° of Fahrenheit; and the engine in every respect not only did its work better, but went more pleasantly. This at once convinced me that a considerable degree of condensation of the steam took place in entering the cylinder, and that I had lost more this way by the coldness of the cylinder, than I

had gained by the increase of load. In short, this single alteration seemed to have unfettered the engine; but in what degree this condensation took place under different circumstances of heat, and where to strike the medium, so as upon the whole to do best, was still unknown to me. But resolving, if possible, to make myself master of the subject, I immediately began to build a small fire-engine at home, that I could easily convert into different shapes for experiments, and which engine was very near ready to set to work in the winter of 1769."

With this experimental engine, which is represented in Plate III. *Steam-Engine*, Mr. Smeaton made a multitude of experiments, which he noted down with great care in tables, and from their results deduced rules for the proportions of the parts of his engines: he afterwards erected many engines of the largest dimensions, which fully verified his experiments: the first of these was at Long Benton colliery, in 1774, which had a 52-inch cylinder, and afterwards a 72-inch, for the empress of Russia, at Cronstadt.

Mr. Smeaton's Experimental Engine.—Plate III. contains an elevation of this engine, shewing all its parts at one view; and, after the minute description which we have given of Mr. Newcomen's engine in Plate II., it is not necessary to enlarge on the particulars of the present. A, B, are the walls of the building; C groundfills, extending from the wall B, to the wall of the boiler or furnace F; D are strong upright timbers, to support the cross-beam *d*, on which the centre of the beam is sustained; P are the cylinder-beams, framed into the upright D, and the walls A, B; and the cylinder G is hung between them by thick cross-planks *q, q*.

M M the great beam, librating on its centre, and formed to arcs of circles at the ends, to which are suspended the chains *b* for the piston, and the chain of the main-pump spear H. It has also attached to it the plug-frame Q, and at the other end an iron rod K, which works the injection or jack-head pump, I, by means of a counter lever *a a*, which brings the rod, *i*, of the pump to a convenient place, near the main-pump O O. The proper distance for the motion of the beam is limited by two iron fids or pins *b, b*, which reach out from each side of the arch-heads, and stop on pieces of wood, supported by the beams S, called the spring-beams. These beams also, which support the upper floor of the house, are let into the walls A, B, at the ends, and rest in the middle on the cross-beam *d*, and are firmly bolted down, as shewn in the drawing.

N is the injection-pipe, 13 the injection-cock, and X the piston water-cock, branching off from the injection-pipe N. L is the injection-cistern, placed in the highest part of the house; *k k* is the pipe from the injection-pump I, by which it is supplied; and T is the waste-pipe, at which the excess of water runs off. The pipe T leads down to the small cistern *z*, which will always be kept full, and the overflow will run down the waste-pipe *l c*, and escape out of doors.

f is the fire-door, and the ash-pit is beneath it: the fire circulates round the boiler, and then passes into the chimney *g*: *x* is a small door at the bottom of the chimney, to clear the foot, and there is also a damper to regulate the draft: *z* is the boiler, and its figure below is shewn by the dotted lines: *v* is a pipe rising from it, which has the safety-valve at the top of it, contained in a box or trough, which carries the steam through the wall at *w*: *n* is the steam-gauge, a small bent glass tube, which contains mercury, and shews the pressure of the steam. The cylinder G, besides the bored part in which the piston works, has a bottom W, screwed on by a flanch at the lower part, and from this bottom part descends the steam-pipe S. The short pipe, 12, joins to the lower end of the injection-pipe NN; and

opposite to this is a similar short pipe, for the snifting-valve. Also from the bottom of the cylinder there descends the sink, or eduction-pipe *m*, which enters the hot-well *R*, and the end is covered with a valve. *S* is the waste-pipe, from which the excess of hot water in the hot-well is carried off into the well *E E*.

As the hot-well is placed so low that the boiler cannot be supplied from it, a small feed-pipe, *p*, proceeds from the lower part of the cylinder, and enters the boiler, having a cock, *p*, to regulate the quantity which shall pass through, and a valve to prevent the water being drawn up from the boiler into the cylinder. In the top of the boiler is the regulator-plate, *7*, to the under surface of which the regulator is fitted: the handle or lever of the regulator is also seen, and the spanner or rod *5*, by which it is alternately moved backwards or forwards by the arms *3* and *4* of the Λ . When its weight or bob, *3*, falls over on either side of the perpendicular, it is checked by the strap *9*: *1* and *2* are the arms or handles by which the Λ is moved when the pins in the plug-beam, *Q*, act upon them, and *6* is a weight to balance the weight of the handles.

10, *11* is the *F*, or lever of the injection-cock; it is connected with the handle of the cock, *13*, by a fork, which cannot be seen; and the end, *11*, is loaded with a sufficient weight to cause its descent, and open the cock, except when it is elevated, by pressing down the end *10*; and when it is held up by the hook *12*, the cock will then be shut; but when the plug-frame rises to its highest, it draws the wire *14*, and lifts the catch *12*, so as to let fall the weight *11*, and opens the cock in an instant.

The action of this engine is apparent after the explanation which we have given of the former engine, and it is only necessary to explain a small machine which is contained in the cistern *V*, called the cataract: it was very commonly used in the engines for the mines in Cornwall, to regulate the motion of the engine to any given number *per* minute, so that the desired quantity of water could be drawn, without wasting steam in drawing more.

The cataract is nothing more than a small tumbling-bob, moving on a centre within the box *V*, in the same manner as the Λ ; but instead of the weight or bob at the top, it has a small box or cup, which is filled with water by a small stream dropping continually from the small cistern *z*, through a cock. The lever, on which the cup is fixed, has a second lever and counter-weight applied to it, which makes it always assume the vertical position, or nearly so, except when the cup is full, and then it is of sufficient weight to make the cataract-tumbler fall over, and in that position the cup inclines so much, that it discharges its contents, and the counter-weight causes its immediate return. The cataract, when it falls over, strikes a piece which is connected with a wire *15*, and this by a lever, *16*, and the second wire, *17*, draws up the catch *12*.

When the engine works with the cataract, the wire *14*, before mentioned, is detached; and in this state we will suppose the regulator open, the injection-cock shut, and the piston to have just arrived at the top of the cylinder. A pin in the plug-beam, *Q*, seizes the handle *1*, overthrows the tumbling-bob, *3*, of the Λ towards the cylinder, and the prong, *3*, of the fork of the Λ draws the rod *5*, and shuts the regulator. In this situation the engine will remain, until the stream, which flows from the cistern *z*,

through the cock, fills the cup at the top of the cataract, and causes it to fall over; it then strikes suddenly on the piece of the wire *15*, and by the lever *16*, and wire *17*, it raises the hook-catch *12*. This lets fall the weight *11*, and opens the injection-cock, to throw a jet in the cylinder, which condenses the steam therein, making the piston to descend; and when it arrives at the bottom, the pin in the plug *Q* depresses *10*, which shuts the injection, and then, by depressing *2*, overthrows the tumbling-bob, and opens the regulator. This admits steam again into the cylinder, and the counter-weight makes the piston return. The cataract returned the instant that its cup inclined so much as to throw out its water, and the cup then began to fill again; but it will not again act, or discharge the injection-cock, until it is quite filled; and the injection-cock will not open till this happens; so that the engine waits at the top of the stroke till the cataract is ready: and this time of waiting can be regulated, by diminishing or increasing the steam which drops down the cock, so as to draw up exactly as much water as drains into the mine.

In 1765, Mr. Smeaton made a portable steam-engine for draining foundations, or other temporary works. It had a pulley or wheel, to receive the chain which communicated motion from the piston to the pump-rod, instead of a beam; and the whole machine being supported in one frame of wood, it had no connection with the building in which it was placed, or it could work all together in the open air. The frame was shaped like the letter *A*, and the vertex supported the pivots of the wheel, whilst the cylinder and pump were bolted down to the groundfills, on which the *A* was erected. The engine in its action was the same as others; the boiler required no setting in brick-work, but was in the shape of a large tea-kettle, and the fire-place was in the centre of it, surrounded on all sides by the water. On one side was an opening for the fire-door, and a large tube or pipe led through the water to a hollow sphere of cast-iron, in which the fire was made, upon a grate; and from the grate another large tube or ash-pit descended perpendicularly through the bottom of the boiler, and was open below to supply air to the fire; also opposite the fire-door was a third large tube or chimney, leading from the sphere through the side of the boiler, and it then turned up in the manner of the spout of a tea-kettle, to carry off the smoke into a tall chimney of brick or of iron-plate.

From Mr. Smeaton's manuscript papers (now in possession of sir Joseph Banks) we gain much practical as well as philosophical information on the atmospheric engines; and as these engines are still used very extensively at coal-mines, we think the publication of the particulars will be of service.

Mr. Smeaton's experiments with his experimental engine were very numerous, and so diversified, as to afford all the information which can be desired upon Newcomen's engine. It would exceed our limits to transcribe many of these experiments; but we think it will be serviceable to give the table of proportions, which he settled from the results of all his experiments, and after which table, between the years 1774 and 1782, he erected no less than eight first rate engines, with cylinders of five and six feet diameters, and many others of smaller dimensions. A full description, with drawings, of one of these engines, is given in the publication of Mr. Smeaton's Reports, 3 vols. 4to. London, 1811.

Mr. Smeaton's Table for the Proportions of the Parts of Newcomen's Engines, deduced from actual Experiments.

Cylinders.			Strokes.		Journey per Minute.	Boilers.		Diameter of Steam-Pipe.	Square Hole for Jet of Injection.	Injection: Water per Stroke.		Boiler's Feed per Stroke.	Coals per Hour.	Pumpage. Cyl. In. Ft.	Great Product per Minute.	Effect per Minute of one Bufile per Hour.
Diameter.	Square of Diameter.	Area in Square Inches.	No.	Length.		Centre- Diameter.	Fire- Surface.			In Ale- Gallons.	Cyl. Inch Ft.					
Inches.	Cir. In.	Sq. In.	$16\frac{1}{2}$	4 0	Feet.	Ft. In.	Sq. Ft.	Inches.	Inches.	.6	18	Cub. In.	Bufile.	Cyl. In. Ft.		231 M.
12	144	113	$16\frac{1}{2}$	4 0	66.	6 0	$37\frac{1}{2}$	2.50	.33	.76	23	12.7	.74	2.592	.171.072	231
14	196	153	16	4 2	67.71	6 6	44	2.78	.375	.93	28	15.9	.91	3.528	.238.881	263
16	256	201	$15\frac{3}{4}$	4 4	69.3	7 0	$51\frac{1}{2}$	3.06	.42	1.13	34	19.7	1.11	4.608	.319.488	288
18	324	254	$15\frac{3}{4}$	4 6	70.88	7 6	$58\frac{1}{2}$	3.35	.47	1.36	41	23.9	1.33	5.832	.413.372	311
20	400	314	$15\frac{3}{4}$	4 8	72.3	8 0	$66\frac{1}{2}$	3.64	.51	1.6	48	28.5	1.56	7.200	.520.800	334
22	484	380	$15\frac{3}{4}$	4 10	73.71	8 6	$75\frac{1}{2}$	3.93	.56	1.86	56	33.6	1.81	8.712	.642.162	355
24	576	452	15	5 0	75.	9 0	84	4.22	.60	2.16	65	39.3	2.08	10.368	.777.600	374
26	676	531	$14\frac{1}{2}$	5 2	76.21	9 6	94	4.52	.645	2.48	74	45.3	2.36	12.168	.927.323	393
28	784	615	$14\frac{1}{2}$	5 4	77.3	10 0	104	4.82	.69	2.82	$84\frac{1}{2}$	52.	2.66	14.112	1.091.528	410
30	900	706	$14\frac{1}{2}$	5 6	78.36	10 6	115	5.12	.735	3.15	93	59.1	2.97	16.200	1.269.432	427
32	1024	814	14	5 8	79.8	11 0	126	5.43	.78	3.56	107	66.8	3.30	18.432	1.462.272	443
34	1156	907	$13\frac{1}{2}$	5 10	80.21	11 6	138	5.74	.825	4.	120	75.	3.64	20.808	1.669.010	459
36	1296	1018	$13\frac{1}{2}$	6 0	81.	12 0	150	6.05	.87	4.46	134	84.	4.00	23.328	1.889.568	472
38	1444	1134	$13\frac{1}{2}$	6 2	81.71	12 6	163	6.37	.91	4.95	148	93.4	4.37	25.992	2.123.806	486
40	1600	1256	13	6 4	82.3	13 0	176	6.69	.95	5.46	164	103.7	4.76	28.800	2.371.200	500
42	1764	1385	$12\frac{1}{2}$	6 6	82.88	13 6	190	7.01	.99	6.03	181	114.6	5.16	31.752	2.631.666	510
44	1936	1520	$12\frac{1}{2}$	6 8	83.3	14 0	204	7.34	1.03	6.63	199	126.5	5.58	34.848	2.904.000	520
46	2116	1662	$12\frac{1}{2}$	6 10	83.71	14 6	219	7.67	1.07	7.26	218	139.	6.01	38.088	3.188.346	531
48	2304	1809	12	7 0	84.3	15 0	234	8.	1.11	7.96	239	152.5	6.46	41.472	3.483.648	539
50	2500	1963	$11\frac{1}{2}$	7 2	84.21	11 0	252	8.33	1.15	8.7	261	166.9	6.92	45.000	3.789.450	548
52	2704	2123	$11\frac{1}{2}$	7 4	84.3	11 6	276	8.66	1.19	9.48	284	182.3	7.40	48.672	4.104.672	555
54	2916	2290	$11\frac{1}{2}$	7 6	84.36	12 0	300	9.	1.225	10.3	310	216.4	7.89	52.488	4.427.888	561
56	3136	2463	11	7 8	84.	12 0	326	9.33	1.26	11.22	336	235.1	8.40	56.448	4.760.448	567
58	3364	2642	$10\frac{3}{4}$	7 10	84.21	12 0	354	9.66	1.295	12.18	363	253.3	8.92	60.552	5.099.084	572
60	3600	2827	$10\frac{3}{4}$	8 0	84.	12 0	384	10.	1.33	13.2	396	276.7	9.46	64.800	5.443.200	575
62	3844	3019	$10\frac{3}{4}$	8 2	83.71	12 0	402	10.33	1.36	14.3	429	299.8	10.58	69.192	5.792.062	579
64	4096	3216	10	8 4	83.3	12 0	426	10.66	1.39	15.46	464	324.3	10.58	73.728	6.144.000	581
66	4356	3421	$9\frac{3}{4}$	8 6	82.88	12 0	450	11.	1.45	16.73	502	350.7	11.16	78.408	6.498.455	583
68	4624	3631	$9\frac{3}{4}$	8 8	82.3	12 0	476	11.33	1.45	18.08	542	378.9	11.76	83.232	6.852.768	583
70	4900	3848	$9\frac{1}{4}$	8 10	81.71	12 0	502	11.66	1.475	19.53	586	409.3	12.37	88.200	7.206.832	583
72	5184	4071	9	9 0	81.	12 0	530	12.	1.50				13.00	93.312	7.558.272	581

The Surface in the Flues is taken at Half.

They have Two Boilers.

The different columns of this table explain themselves, except the great product *per* minute. This is the effect of the engine expressed in a convenient manner, to separate it from all considerations of the diameter or lift of the pumps, or of the number of strokes which the engine makes in a minute; being the multiple of all these, and is thus obtained. Multiply the square of the diameter of the cylinder in inches, by the pressure on each square inch of the piston, not expressed in pounds weight, but in the height of a column of water in feet; and this again is multiplied by the velocity of the motion of the piston *per* minute. For example, a 26-inch cylinder: square of diameter, (676) \times 18 feet, the pressure *per* square inch in feet of water, = 12168 \times 76.21 feet, the journey *per* minute, = 927323, the great product *per* minute, as *per* table. The table is calculated upon the supposition that the pressure upon each square inch of the piston is 8 lbs. avoirdupois, or 18 feet column of water.

The last column, or effect *per* minute of one bushel *per* hour, is a comparative view of the effect of different-sized engines, shewing the advantages of large engines in respect to small, in the quantity of work they will effect in proportion to the coals they consume.

To find the number of bushels of coals which any of the engines will consume *per* hour, calculate the internal surface of the cylinder in square inches, and add to it three times the square of the diameter, to allow for the piston bottom, cylinder bottom, and the surface of the pipes which are within the cylinder. Next calculate the solid content of the cylinder in cubic inches, and find the proportion between the superficial and the solid measure of the cylinder: according to the number of this proportion, find a number in the following table for a divisor.

Proportion of the Surface of Cylinder to its Capacity square and cubic Inches.	Effect of one Bushel <i>per</i> Hour.	Differences.
	98	
2	188	90
3	273	85
4	349	76
5	414	65
6	468	54
7	512	44
8	545	33
9	567	
10	578	
11	578	
12	572	

Lastly, cut off three places of figures from the great product *per* minute, and dividing by the divisor, the quotient will be the effect of one bushel *per* minute.

For example, a 72-inch cylinder: its circumference will be 226.3, which, multiplied by 135 inches, the length, gives 30550 square inches; and adding thereto 15552, which is three times the square of the diameter, we have 46102 superficial inches; and the content of the cylinder is 549652 cubic inches, which is 11.9 times the number of the superficial inches. By seeking in the last table for 11.9 or 12, we find the number 572 for the divisor of the

great product, after cutting off its three last figures, viz. $7558 \div 572 = 13$ bushels *per* hour.

By this way of finding the proportion between the surface and the content of the cylinder, an allowance is made for the loss of steam which takes place from condensation, when it enters into the cylinder at every stroke, after it has been cooled by the injection thrown into it.

The quantity is very considerable, and forms the greatest objection to this form of the steam-engine. An attentive observation to the action of an engine will shew that there is a waste, but not the quantity in which it takes place. The moment the regulator is opened, when the piston is at the bottom of the stroke, the steam may be perceived to issue from the snifting-valve with a strong puff, because the steam is more elastic than air by one or two pounds *per* square inch; but as the piston rises, this steam diminishes, and soon ceases, and no more steam will issue during the whole rise of the piston.

To ascertain the quantity of this loss by condensation, it becomes first necessary to know to what degree water is expanded, when converted into steam, at the pressure of the atmosphere; and compare this with the degree of expansion which it requires to convert the water, which the boiler consumes in a given time, into such a quantity of steam as will fill the cylinder the requisite number of times in the same period.

Mr. Beighton made an experiment at Griff engine, in Warwickshire, on the degree of rarefaction of water when converted into steam, but without determining the temperature. The pressure of the steam was just one pound upon the square inch, as he determined by the steelyard of the safety-valve; and by our second table, we find this to denote a temperature of about 216°. The cylinder of the engine contained 113 gallons of steam at every stroke, which, at 16 strokes *per* minute, is equal to 1808 ale-gallons, or $1808 \times 8 = 14464$ pints of steam *per* minute. He found that the necessary supply of fresh water for the boiler, under these circumstances, was about five pints *per* minute, to keep the surface of the water at a constant level; therefore, the relative bulks of the steam of one pound *per* inch pressure, and the water from which it was produced, were as 5 to 14464, or as 1 to 2893 nearly. By an unaccountable mistake, Defaguliers, who relates the above experiment, deduces from the same data, that the expansion is 13388, a number which has been frequently quoted by other writers. Mr. Beighton's experiment cannot be admitted as conclusive, because the cylinder being cooled by the condensing water at every stroke, the steam would be condensed, and lose much of its bulk in entering into the cold cylinder. But without making any allowance for that loss, Mr. Beighton's experiment makes a greater degree of expansion than has been found by others; and we should not have mentioned this experiment at all, had it not been so frequently quoted after Defaguliers with his enormous error, even by Belidor, Prony, and other foreign writers.

Mr. Smeaton made some experiments by weighing a Florence flask of four inches diameter, first when it was perfectly dry and empty, and afterwards when it was full of water; then pouring out all the water, except a small quantity, he put the globe on the fire, and made it boil strongly, till the last drop of water disappeared, and at that instant he stopped up the mouth to retain the steam which was within it. The flask being now weighed, gave the difference of weight between the flask filled with water and with steam of an elastic force equal to that of atmospheric air; and deducting the weight of the empty flask from each of these experiments,

Mr. Smeaton's Table for the Proportions of the Parts of Newcomen's Engines, deduced from actual Experiments.

Cylinders.			Strokes.		Journey per Minute.	Boilers.		Diameter of Steam-Pipe.	Square Hole for Jet of Injection.	Injection-Water per Stroke.		Boiler's Feed per Stroke.	Coals per Hour.	Pumpage.	Great Product per Minute.	Effect per Minute of one Bushel per Hour.
Diameter.	Square of Diameter.	Area in Square Inches.	No.	Length.		Centre- Diameter.	Fire- Surface.			In Ale- Gallons.	Cyl. Inch Ft.					
Inches.	Cir. In.	Sq. In.	Ft.	In.	Feet.	Ft.	Sq. Ft.	Inches.	Inches.			Cub. In.	Bushels.	Cyl. In. Ft.		M.
12	144	113	16 $\frac{1}{2}$	4 0	66.	6 0	37 $\frac{1}{2}$	2.50	.33	.6	18	12.7	.74	2.502	.171.072	231
14	196	153	16 $\frac{1}{2}$	4 2	67.71	6 6	44	2.78	.375	.76	23	15.9	.91	3.528	.238.881	263
16	256	201	16	4 4	69.3	7 0	51 $\frac{1}{2}$	3.06	.42	.93	28	19.7	1.11	4.608	.319.488	288
18	324	254	15 $\frac{3}{4}$	4 6	70.88	7 6	58 $\frac{1}{2}$	3.35	.47	1.13	34	23.9	1.33	5.832	.413.372	311
20	400	314	15 $\frac{3}{4}$	4 8	72.3	8 0	66 $\frac{1}{2}$	3.64	.51	1.36	41	28.5	1.56	7.200	.520.800	334
22	484	380	15 $\frac{3}{4}$	4 10	73.71	8 6	75 $\frac{1}{2}$	3.93	.56	1.6	48	33.6	1.81	8.712	.642.162	355
24	576	452	15	5 0	75.	9 0	84	4.22	.605	1.86	56	39.3	2.08	10.368	.777.600	374
26	676	531	14 $\frac{3}{4}$	5 2	76.21	9 6	94	4.52	.645	2.16	65	45.3	2.36	12.168	.927.323	393
28	784	615	14 $\frac{3}{4}$	5 4	77.3	10 0	104	4.82	.69	2.48	74 $\frac{1}{2}$	52.	2.66	14.112	1.091.528	410
30	900	706	14 $\frac{3}{4}$	5 6	78.36	10 6	115	5.12	.735	2.82	84 $\frac{1}{2}$	59.1	2.97	16.200	1.269.432	427
32	1024	814	14	5 8	79.8	11 0	126	5.43	.78	3.18	95 $\frac{1}{2}$	66.8	3.30	18.432	1.462.272	443
34	1156	907	13 $\frac{3}{4}$	5 10	80.21	11 6	138	5.74	.825	3.56	107	75.	3.64	20.800	1.669.010	459
36	1296	1018	13 $\frac{3}{4}$	6 0	81.	12 0	150	6.05	.87	4.	120	84.	4.00	23.328	1.889.568	472
38	1444	1134	13 $\frac{3}{4}$	6 2	81.71	12 6	163	6.37	.91	4.46	134	93.4	4.37	25.992	2.123.806	486
40	1600	1256	13	6 4	82.3	13 0	176	6.69	.95	4.95	148 $\frac{1}{2}$	103.7	4.76	28.800	2.371.200	498
42	1764	1385	12 $\frac{3}{4}$	6 6	82.88	13 6	190	7.01	.99	5.46	164	114.6	5.16	31.752	2.631.666	510
44	1936	1520	12 $\frac{3}{4}$	6 8	83.3	14 0	204	7.34	1.03	6.03	181	126.5	5.58	34.848	2.904.000	520
46	2116	1662	12 $\frac{3}{4}$	6 10	83.71	14 6	219	7.67	1.07	6.63	199	139	6.01	38.088	3.188.346	531
48	2304	1809	12	7 0	84.3	15 0	234	8.	1.11	7.26	218	152.5	6.46	41.472	3.483.648	539
50	2500	1963	11 $\frac{3}{4}$	7 2	84.21	11 0	252	8.33	1.15	7.96	239	166.9	6.92	45.000	3.789.450	548
52	2704	2123	11 $\frac{3}{4}$	7 4	84.3	11 6	276	8.66	1.19	8.7	261	182.3	7.40	48.672	4.104.672	555
54	2916	2290	11 $\frac{3}{4}$	7 6	84.36	12 0	300	9.	1.25	9.48	284 $\frac{1}{2}$	198.7	7.89	52.488	4.427.888	561
56	3136	2463	11	7 8	84.	12 0	326	9.33	1.26	10.3	310	216.4	8.40	56.448	4.760.448	567
58	3364	2642	10 $\frac{3}{4}$	7 10	84.21	12 0	354	9.66	1.295	11.22	336 $\frac{1}{2}$	235.1	8.92	60.552	5.099.084	572
60	3600	2827	10 $\frac{3}{4}$	8 0	84.	12 0	384	10.	1.33	12.18	363 $\frac{1}{2}$	253.3	9.46	64.800	5.443.200	575
62	3844	3019	10 $\frac{3}{4}$	8 2	83.71	12 0	402	10.33	1.36	13.2	396	276.7	10.01	69.192	5.792.062	579
64	4096	3216	10	8 4	83.3	12 0	426	10.66	1.39	14.3	429	299.8	10.58	73.728	6.144.000	581
66	4356	3421	9 $\frac{3}{4}$	8 6	82.88	12 0	450	11.	1.45	15.46	464	324.3	11.16	78.408	6.498.455	581
68	4624	3631	9 $\frac{3}{4}$	8 8	82.3	12 0	476	11.33	1.45	16.73	502	350.7	11.76	83.232	6.852.768	583
70	4900	3848	9 $\frac{3}{4}$	8 10	81.71	12 0	502	11.66	1.475	18.08	542 $\frac{1}{2}$	378.9	12.37	88.200	7.206.822	583
72	5184	4071	9	9 0	81.	12 0	530	12.	1.50	19.53	586	409.3	13.00	93.312	7.558.272	581

The Surface in the Flues is taken at Half.

These have Two Boilers.

The different columns of this table explain themselves, except the great product *per* minute. This is the effect of the engine expressed in a convenient manner, to separate it from all considerations of the diameter or lift of the pumps, or of the number of strokes which the engine makes in a minute; being the multiple of all these, and is thus obtained. Multiply the square of the diameter of the cylinder in inches, by the pressure on each square inch of the piston, not expressed in pounds weight, but in the height of a column of water in feet; and this again is multiplied by the velocity of the motion of the piston *per* minute. For example, a 26-inch cylinder: square of diameter, (676) \times 18 feet, the pressure *per* square inch in feet of water, = 12168 \times 76.21 feet, the journey *per* minute, = 927323, the great product *per* minute, as *per* table. The table is calculated upon the supposition that the pressure upon each square inch of the piston is 8 lbs. avoirdupois, or 18 feet column of water.

The last column, or effect *per* minute of one bushel *per* hour, is a comparative view of the effect of different-sized engines, shewing the advantages of large engines in respect to small, in the quantity of work they will effect in proportion to the coals they consume.

To find the number of bushels of coals which any of the engines will consume *per* hour, calculate the internal surface of the cylinder in square inches, and add to it three times the square of the diameter, to allow for the piston bottom, cylinder bottom, and the surface of the pipes which are within the cylinder. Next calculate the solid content of the cylinder in cubic inches, and find the proportion between the superficial and the solid measure of the cylinder: according to the number of this proportion, find a number in the following table for a divisor.

Proportion of the Surface of the Cylinder to its Capacity in square and cubic Inches.	Effect of one Bushel <i>per</i> Hour.	Differences.
1	98	
2	188	90
3	273	85
4	349	76
5	414	65
6	468	54
7	512	44
8	545	33
9	567	22
10	578	11
11	578	0
12	572	8

Lastly, cut off three places of figures from the great product *per* minute, and dividing by the divisor, the quotient will be the effect of one bushel *per* minute.

For example, a 72-inch cylinder: its circumference will be 226.3, which, multiplied by 135 inches, the length, gives 30550 square inches; and adding thereto 15552, which is three times the square of the diameter, we have 46102 superficial inches; and the content of the cylinder is 549652 cubic inches, which is 11.9 times the number of the superficial inches. By seeking in the last table for 11.9 or 12, we find the number 572 for the divisor of the

great product, after cutting off its three last figures, viz. $7558 \div 572 = 13$ bushels *per* hour.

By this way of finding the proportion between the surface and the content of the cylinder, an allowance is made for the loss of steam which takes place from condensation, when it enters into the cylinder at every stroke, after it has been cooled by the injection thrown into it.

The quantity is very considerable, and forms the greatest objection to this form of the steam-engine. An attentive observation to the action of an engine will shew that there is a waste, but not the quantity in which it takes place. The moment the regulator is opened, when the piston is at the bottom of the stroke, the steam may be perceived to issue from the snifting-valve with a strong puff, because the steam is more elastic than air by one or two pounds *per* square inch; but as the piston rises, this steam diminishes, and soon ceases, and no more steam will issue during the whole rise of the piston.

To ascertain the quantity of this loss by condensation, it becomes first necessary to know to what degree water is expanded, when converted into steam, at the pressure of the atmosphere; and compare this with the degree of expansion which it requires to convert the water, which the boiler consumes in a given time, into such a quantity of steam as will fill the cylinder the requisite number of times in the same period.

Mr. Beighton made an experiment at Griff engine, in Warwickshire, on the degree of rarefaction of water when converted into steam, but without determining the temperature. The pressure of the steam was just one pound upon the square inch, as he determined by the steelyard of the safety-valve; and by our second table, we find this to denote a temperature of about 216°. The cylinder of the engine contained 113 gallons of steam at every stroke, which, at 16 strokes *per* minute, is equal to 1808 ale-gallons, or $1808 \times 8 = 14464$ pints of steam *per* minute. He found that the necessary supply of fresh water for the boiler, under these circumstances, was about five pints *per* minute, to keep the surface of the water at a constant level; therefore, the relative bulks of the steam of one pound *per* inch pressure, and the water from which it was produced, were as 5 to 14464, or as 1 to 2893 nearly. By an unaccountable mistake, Defaguliers, who relates the above experiment, deduces from the same data, that the expansion is 13388, a number which has been frequently quoted by other writers. Mr. Beighton's experiment cannot be admitted as conclusive, because the cylinder being cooled by the condensing water at every stroke, the steam would be condensed, and lose much of its bulk in entering into the cold cylinder. But without making any allowance for that loss, Mr. Beighton's experiment makes a greater degree of expansion than has been found by others; and we should not have mentioned this experiment at all, had it not been so frequently quoted after Defaguliers with his enormous error, even by Belidor, Prony, and other foreign writers.

Mr. Smeaton made some experiments by weighing a Florence flask of four inches diameter, first when it was perfectly dry and empty, and afterwards when it was full of water; then pouring out all the water, except a small quantity, he put the globe on the fire, and made it boil strongly, till the last drop of water disappeared, and at that instant he stopped up the mouth to retain the steam which was within it. The flask being now weighed, gave the difference of weight between the flask filled with water and with steam of an elastic force equal to that of atmospheric air; and deducting the weight of the empty flask from each of these experiments,

experiments, it gave the proportion of the bulk of the steam to that of the water: this, by a mean of six different experiments, he determined to be as $\frac{1}{11}$. But suspecting that some air was contained in the flask along with the steam, he inverted the mouth of it in water when it was filled with the hot steam, and found it to draw up the water in the same manner as described by captain Savery; but it was not quite filled with water, for a small bubble of air remained in the flask, and this he estimated to be such a portion of the whole content, as induced him to reduce his estimate of the expansion from 2459 times to 1800 times; and this number, the same number that Mr. Watt had determined, he used in his calculations.

His investigation of the quantity of steam destroyed by a given surface of the cold cylinder was as follows. The cylinder of the experimental engine was 9.9 inches diameter and 50 inches long: making the requisite additions to its bottom and piston, the internal surface was 2340 square inches, and the solid content was 3940 cubic inches. The quantity of water necessary to supply the boiler at each stroke was found to be 8.5 cubic inches: therefore, $3940 \div 8.5 = 463$ times, which the 8.5 cubic inches of water must have expanded to fill the cylinder at each stroke. But supposing the water to have expanded 1800 times, the 8.5 inches $\times 1800 = 15300$ cubic inches of steam produced, which is 3.88 times the quantity employed to fill the cylinder. The difference of these numbers, viz. $15300 - 3940 = 11360$ inches of steam condensed and lost. This, divided by the number of superficial inches on the surface of the cylinder, gives 4.9 cubic inches condensed by every square inch of surface.

It will be readily seen, that the proportion between the quantity of steam which must be produced, and the quantity which will be employed, will be less in large cylinders than in small ones; and the above is the extreme case; and in a similar trial of a 52-inch cylinder, he found the waste to be only 2.7 cubic inches for each inch of surface. Hence we see the reason for Mr. Smeaton's rule of making the proportion of the surface of the cylinder to its capacity the ground-work for the calculation of the quantity of coals.

In common engines, which are loaded to seven or eight pounds upon the inch, and are of a middle size, the quantity of steam which is condensed in restoring to the cylinder the heat which it had lost, is equal to the full contents of the cylinder, besides what it really required to fill it; so that twice the contents of the cylinder are employed to make it raise a column of water equal to about seven or eight pounds for each square inch of the piston; or to take it more simply, a cubic foot of steam makes a sufficient vacuum to raise a cubic foot of water about eighteen feet high, besides overcoming the friction of the engine, and the resistance of the water to motion.

In all Mr. Smeaton's experiments he observed the quantity of water which was evaporated in proportion to the coals, and found by a mean of a great number of experiments, that a bushel of coals evaporated 12700 cubic inches of water, or 7.35 cubic feet; and estimating the expansion at 1800 times, the bushel of coals will produce 13230 cubic feet of steam, of little more in elasticity than the atmosphere, and about 214° of Fahrenheit's thermometer.

The Work actually performed by Atmospheric Engines in proportion to the Coals.—We shall first give the results of the performance of some old engines, according to Mr. Smeaton's account, before he began his improvements. The engine at Long Benton colliery, which was considered as one of the best in the neighbourhood of Newcastle, was tried

by Mr. Smeaton in 1772; it was of the following dimensions. Cylinder 52 inches diameter, stroke 7 feet. The pump was 12 inches diameter, and drew the water 61 fathoms high; and also an injection-pump 8 inches diameter, and 5 feet $7\frac{1}{2}$ inches stroke, which raised water 58 feet. This engine consumed 8 bolls (of 2 cwt. 1 qr. $21\frac{1}{2}$ lbs. each) of coals, such as are generally used for engines, in two hours and two minutes, when working at the rate of from $7\frac{1}{2}$ to 8 strokes per minute, or $7\frac{1}{2}$ per minute at the medium.

The computations from these data are first to ascertain the real weight of water in the pumps: the main pump being 12 inches diameter, and the injection-pump 8, the proportion of the areas of the two will be as the squares of their diameters, and their load in proportion to their height of column; therefore, as $144 : 64 :: 58 \text{ feet high} : 25.7 \text{ feet}$; that is, the whole load of the injection-pump will be equal 25.7 feet of the main column of 12 inches diameter; but this is, provided that the length of stroke was the same in both.

To reduce them to one, say as a 7-foot stroke, or 84 inches, $: 67.5 \text{ in.} :: 25.7 \text{ ft.} : 20.7 \text{ feet of the column of the main pumps, say 21 feet.}$

Hence, the whole load consists of the main column of 12 inches diameter, and 61 fathoms or 366 feet, and the injection-pump equal to 21 feet thereof, $366 + 21 \text{ feet} = 387 \text{ feet.}$

To obtain what Mr. Smeaton calls the great product, by which the powers of different engines can be compared, multiply the square of the pump's diameter 144 inches $\times 387 \text{ feet lift} = 55728$, which multiplied by a 7-foot stroke $= 390096$, and again by 7.75 strokes per minute $= 3023244$, the whole product or effect of the engine, without regard to coals, or without any allowance for the weight of the pump-rods, and the counterpoise of the engine.

The quantity of coals was 2 cwt. 1 qr. $21\frac{1}{2}$ lbs. $= 273\frac{1}{2}$ lbs. $\times 8 \text{ bolls} = 2188 \text{ lbs.}$ which divided by 88 lbs., the weight of a London bushel, gives 24.86 bushels consumed in the whole time of the experiment, viz. two hours and two minutes, or 122 minutes.

To find the coals for one hour's work, say as 122 minutes $: 60 \text{ min.} :: 24.86 \text{ bushels} : 12.22 \text{ bushels per hour.}$

Lastly, the whole product 3023244 , divided by 12.22, gives 247401 for the product or effect of one bushel of coals per hour.

This engine was rebuilt according to Mr. Smeaton's plan, with the same cylinder of 52 inches and 7-foot stroke, but the pumps were enlarged to 12.2 inches diameter, and lifted in two columns each 24 fathoms 4 feet high. The injection-pump was 7 inches diameter, 5 feet 6 inches stroke, and lifted 70 feet 7 inches high.

In 1774 Mr. Smeaton tried the experiment, and found that when this new engine was working at the rate of twelve strokes per minute, 2 cwt. 1 qr. 16 lbs. of the common engine coals supplied it 22 minutes.

From this he made a similar computation to those for the former engine. Square of 12.2 inches the diameter of the main pumps 148.84; square of 7 inches the diameter of injection-pump 49; its lift $70\frac{1}{2}$ feet. Then say as $148.84 : 49 :: 70\frac{1}{2} : 23.21 \text{ feet of the main column, if the lengths of the strokes were equal; but as they are not, say as the long stroke } 84 \text{ in.} : 66 \text{ in.} :: 23.21 \text{ ft.} : 18.2$; therefore the load of the injection-pump is equal to the load of 18.2 feet of height of the main column.

The total load then is equal to a barrel 12.2 inches diameter, twice 24 fathoms 4 feet, or 296 feet + 18 feet, viz. 314 feet of lift.

To obtain the great product, multiply the square of the pump's diameter 148.84 by 314 feet; the height lifted =

46735.76, which multiplied by 7-feet stroke = 327150.32; and again by 12 strokes *per* minute = 3925803.84, the whole product or effect of the engine, without regard to coals, or without allowance for the weight of the pump-rod, nearly 3 tons, and the counter-weight of the engine.

For the quantity of coals 2 cwt. 1 qr. 16lbs., or 268lbs., divide it by 88lbs., the weight of a London bushel, and it makes 3.05 bushels consumed in 22 minutes, the time of the experiment; therefore say, as 22 min. : 60 min. :: 3.05 : 8.32 bushels *per* hour.

Lastly, the whole product 3925803.84, divided by 8.32, gives 471851 for the product, or effect of one bushel of coals *per* hour. Therefore the effect of this new engine, compared with the former engine, is as 471851 to 247401.

To this computation, which is chiefly comparative between the two engines, we may add the following, to shew the pressure upon each square inch of the piston. The area of the 52-inch cylinder is $52 \times 52 = 2704 \times .7854 = 2123$ square inches.

The weight of the column of water in the pumps, 12.2 inches diameter, will be about 50.9lbs. weight for each foot in height. For $12.2 \times 12.2 = 148.84 \times .7854 = 116.8$, the square inches in the area of the pump. Now, a cubic foot of water weighs $62\frac{1}{2}$ pounds nearly; therefore divide 62.5lbs. by 144, the square inches in a square foot, and it will give .434lbs., which is the weight of a column of water one inch bafe and one foot high. Multiply $116.8 \times .434 = 50.7$ lbs., the weight of the column of water in the pumps a foot high; and this multiplied by 314 feet, the whole lift equals 15919lbs., the total weight of water. Divide this number by 2123, the number of square inches in the surface of the piston, and it will give 7.48lbs. for the pressure upon each square inch, or $7\frac{1}{2}$ very nearly.

Another method of readily finding the pressure *per* square inch in the piston is thus. As the square of the diameter of the cylinder ($52 \times 52 =$) 2704 is to the square of the diameter of the pump ($12.2 \times 12.2 =$) 148.84, so is the height which the pump lifts, 314 feet, to 17.24, the height of a column of water, which, if it rested on the piston, would balance the water in the pump. Then multiply 17.24 feet by .434lbs., the weight of an inch square of water one foot high, and the result is 7.48lbs. for the pressure *per* square inch, the same as before.

Since Mr. Watt introduced his improved engines, it has been customary to compare their effects by the number of pounds of water which they can raise to one foot high by the consumption of a bushel of coals, without regarding the time in which it is expended. To reduce these two engines to that standard, we must say the first engine consumed 24.86 bushels in 122 minutes; therefore, as 24.86 bush. : 122 min. :: 1 bush. : 49 min.; that is, one bushel will last 49 minutes. At every stroke, the pump draws up a cylinder of water, 12 inches diameter and 7 feet long, 387 feet high. This cylinder of water will weigh 343lbs.; for $12 \times 12 = 144 \div .7854 = 113$ inches, the area of the pump. This, multiplied by .434lbs., the weight of a column one inch square, and one foot high, will be 49lbs.; and again, multiplied by 7 feet for the length, will equal 343lbs.

The quantity of coals consumed in the first experiment was 24.86 bushels: the experiment lasted 122 minutes, during which time the engine, working at $7\frac{1}{2}$ strokes *per* minute, made 945 strokes; then say, as 24.86 bush. : 945 strokes :: 1 bush. : 38; therefore the engine makes 38 strokes for every bushel of coals which it consumes.

At every stroke the engine raises 343lbs. of water 387 feet. Multiply 343 by 38, the number of strokes, and it gives 13034lbs., lifted 387 feet by each bushel of coals. Lastly,

$13034 \times 387 = 5,044,158$ lbs. of water raised one foot high with a bushel of coals.

The new engine consumed 3.05 bushels in 22 minutes, during which time it worked 12 strokes *per* minute; it is therefore 264 strokes: then say, as 3.05 bush. : 264 strokes :: 1 bush. : 86.5, the number of strokes which the engine will make for each bushel it consumes.

At every stroke the engine raises a cylinder of water, 12.2 inches diameter, 7 feet long, and weighing 354.8lbs. 314 feet high. Multiply this 354.8lbs. by the 86.5 strokes which the engine makes for each bushel of coals, and we have 30690, the number of pounds of water lifted 314 feet by each bushel of coals. And lastly, 30690×314 feet = 9,636,660lbs. of water lifted one foot high with each bushel of coals.

Mr. Smeaton's Directions for making Engines. — Mr. Smeaton made his engines with a wooden bottom to the piston, as we have before noticed. This was because wood communicates heat much less rapidly than metals. The piston is kept much cooler than any other part to which the steam has direct access, not only from the water which is poured upon it to keep it tight, and prevent the leakage of air into the cylinder, but also because it receives the first and most direct action of the cold injection-water: and as the steam in entering the cylinder through the steam-pipe first meets the cold surface of the piston, it is thereby condensed in a greater degree than by an equal portion of the internal surface of the cylinder. By covering the bottom of the piston with wood, it will receive or conduct less heat from the steam; and for the same reason, the cold water, when it is thrown up against the piston, will be less heated by the contact of it, the wood acting as a neutral body on the fluids, which alternately act against it.

The injection-cap, or jet, according to Mr. Smeaton, should be a square hole through a brass plate, and rounded from the under side, that it may throw up a full bore. The middle of the jet should not be directed to strike the centre of the piston bottom, but it should rise perpendicularly, so as to strike the piston bottom at right angles. That part of the injection-pipe which is within the cylinder should be made of wood, or if of metal, wrapped round with tarred marline, or small rope, to separate the metal of the pipe from the contact of the steam, or hot water, which not only saves the condensation of some steam, but by preventing the pipe becoming hot, that portion of injection-water which is contained in the pipe is kept cool, and the steam which afterwards flows through the pipe will enter in its coolest state. The injection-cistern should be placed as high as the building will admit, so as to give a smartness to the jet.

A pipe should be applied beyond the snifting-valve, with a cock in it, which being partially closed, the snifting can be regulated, if it should be found too great, so as to emit more steam than is requisite. Mr. Smeaton also placed a small air-cock on the upper part of the eduction-pipe, or some other part having free communication with the cylinder, for the largest engine. This was to be only of the size of a small common beer-cock; and when the snift was properly regulated, this cock was to be opened as much as it could be, to allow the piston to come fully down into the cylinder. We suppose this air-cock must have been found practically beneficial, or such an experimental engineer as Mr. Smeaton would have discontinued to recommend it: but we do not know on what principles the admission of air could be serviceable, unless it was to diminish the descending power of the piston when it arrived near the bottom of the cylinder, and thus diminish that acceleration of the piston, of which

we have before spoken in the description of the action of the engine.

Lastly, in adjusting the engine to its work, to determine the proper degree of counter-weight, it was to be put together, and the pumps filled with water, but the buckets without the leathers, and the piston without any packing. In this state, a weight, equal to about 1lb. *per* square inch, being laid upon the piston, the engine was ballasted at either end of the beam, as it might require, until it was found in exact balance. Then, when the piston was relieved from its weight, it would have a counter-weight tending to draw it up with a force equal to 1lb. *per* square inch. This was for engines of the largest dimensions; but as the proportion of loss by friction of the piston and buckets is greater in small cylinders and pumps, smaller engines must have 1½lb., and the smallest engines 2lbs. *per* inch. When it is not convenient to fill the pumps with water up to the top, allowance must be made for the difference of the pump-rods not being immersed.

Mr. Smeaton expected his engines, which were calculated to be loaded with a neat burden of 8lbs. *per* square inch, would, with the counter-weight as above, make their returning stroke rather quicker than the working stroke, and this he preferred.

The proper proportion of the counter-weight has been a matter of much mathematical investigation by writers on the engine, particularly M. Boffut; but it depends upon so many contingent circumstances, that it would be impossible to apply any theorem to practice, even if the theory were established; and the adjustment is easily ascertained by experiment.

The design of the engineer in giving or allowing a preponderancy to the outer end of the beam, is simply that the buckets may descend, and that the piston may rise and allow the steam to fill the cylinder, without any further combination of apparatus being employed for that purpose. Now let us observe its operation, and the manner of adjusting its quantity in an engine's first setting to work. Suppose the water already up to the top of the pump: the steam being admitted into the cylinder till it has driven out the air, the operator shuts the steam-cock, without supplying any injection; and the engine will make its first stroke, though very quietly, by the external condensation from the surface of the cylinder: he then allows steam again to enter the cylinder, and according to the piston's tendency to rise, he suits his judgment to the degree of counter-weight necessary: if it rises too slow, he puts iron or other ballast upon the pump-end of the beam; and if it rises too quick, he places these weights on the piston-end. We have then two important circumstances to attend to in this regulation. First, that the pump-bucket shall descend as quick as it can, but without such force as shall occasion a violent shock to stop the motion at the end of the strokes; and secondly, that the piston shall not be drawn up faster than the steam-regulator (with the degree of opening that is given to it) can supply steam; for that would impede the discharging functions of the engine, or getting rid of the air and condensing water; and unless these are performed punctually, the engine soon ceases to work. Now neither the air nor the water can be discharged instantaneously from the cylinder, but require a certain time, in proportion to the quantity of each, and the degree of strength in the steam; and therefore the piston must not rise so quick as to prevent the steam acting on the air and condensing water, which it will do if the engine has too great a counter-weight, and the steam is low; for if the piston ascends faster than the boiler supplies steam, there can be

no discharge, and after a stroke or two the engine will stop.

But this is on the supposition that the engine is working with its full intended velocity. When an engine is erected on a mine or pit which is sinking, the quantity of water to be lifted by the pump being small, the engine must work slow, and the counter-weight must be in proportion; the beam will nevertheless require an extra counterpoise at the pump-end, because of the lightness of the pump-rods; but as the mine or pit becomes of greater depth, and successive lengths of rods are applied for the different lifts of pumps, the weight must be diminished, and at length transferred to the piston-end of the beam, in such quantity as to keep the engine under command; for as the velocity of the returning stroke depends upon the quantum of counter-weight, this must be regulated according to the quantity of water which this engine has to draw, or rather to the number of strokes the engine is to make in a minute. As this velocity is to be increased when the quantity of water increases, a greater counter-weight must be added; but it is not until the engine works at its intended load, that the counter-weight must be brought to the degree we have mentioned.

While an engine is working, as we have supposed, with a small portion of its full load, the injection must be very sparingly applied, so as to condense imperfectly within the cylinder, or the piston will descend with such velocity, and strike upon the spring-beams with such violence, as to beat every thing to pieces.

When a mine is going down, and the engine-shaft receives all the water from the different parts of the mine, the quickness of the engine's stroke must depend upon the uniform influx of the water, and the engine must be so accurately regulated to this quantity of water, as to sup it up at every stroke. Now if this supping up is violent, the air will be drawn into the pumps at the conclusion of every stroke, and cause the engine to work irregularly; and, on the other hand, if the strokes of the engine are not quick enough, the water will gain on the miners and prevent their working. The velocity, as we have before stated, must be regulated by the quantity of injection which will determine the motion of the stroke, and the counter-weight will regulate the time of the returning stroke: but a much better regulation of the velocity of the engine can be attained by the character, which we have before described.

Even when the engine comes to work with its full load and counter-weight, and when a proper injection is allowed to condense fully, the engine-man can retard or accelerate the returning strokes of the engine, in some degree, by the regulation of the fire; for if the engine should return too quick, he lets down the damper in the flue of the chimney; or if it is too slow, he raises the damper. By these means he can vary the action of the steam, on the lower side of the piston, from one to two pounds on the inch, greater than the pressure of the atmosphere, which in a sixty-inch cylinder will amount to 2800 pounds; and is a sufficient latitude to make the engine return very quick or very slow, but does not alter the period of the working of the stroke.

Other Improvements on Newcomen's Engine.—Mr. Smeaton's improvements on the engine, as we have shewn, consisted only in proportioning its parts, but without altering any thing in its principle.

In 1759, Mr. James Brindley, the engineer who designed and executed the duke of Bridgewater's canal, obtained a patent for improvements in the structure of the fire-engine. The boiler he proposed to be made of wood and stone, with a cast-iron stove or fire-place within of it, and sur-

rounded on all sides, so as to give its heat to the water. The chimney was an iron pipe or tube, also immersed in the water of the boiler. This plan he expected would save a considerable portion of the fuel. The feeding-pipe for the boiler was to be made with a clack, to be opened and shut by a float upon the surface of the water in the boiler, so as to supply it with water always to the same level, without any care on the part of the engine-man. The great chains for the arches of the beam were to be of wood, and his pumps were also to be made of wooden staves hooped together. These are all the improvements mentioned in the specification of his patent: but in the new edition of the *Biographia Britannica*, we are informed that, in 1756, Mr. Brindley undertook to erect a steam-engine near Newcastle-under-Lyne upon a new plan. The boiler of it was made with brick and stone, instead of iron plates, and the water was heated by internal iron flues of a peculiar construction, by which contrivances the consumption of fuel necessary for working a steam-engine was reduced one-half. He introduced also into his engine wooden cylinders, made in the manner of coopers' ware, instead of iron ones, the former being cheaper and more easily managed in the shafts; and he likewise substituted wood for iron in the chains which worked at the end of the beam. He had formed designs of introducing other improvements into the construction of this useful engine, but was discouraged by obstacles that were thrown in his way.

The most important improvement in the atmospheric engine was the application of it, by means of a crank and fly-wheel, to the purpose of turning mills. This was not much of an invention to any one who had considered the action of a foot-lathe; but it does not appear to have been put in practice till a late period, or brought into any extensive use till after Mr. Watt invented his engine. Mr. Jonathan Hulls had a patent in 1736, for working rowing-wheels at the side or head of a boat by the force of Newcomen's engine, and we believe he proposed to employ a crank, to produce the rotatory motion of his wheels.

In 1759, Mr. Keane Fitzgerald proposed, in the *Philosophical Transactions*, a contrivance to work the ventilator by the fire-engine, for the benefit of those who work in mines, where it is employed to draw off the water. By this contrivance the lever of the fire-engine, which works up and down, and performs at a medium about twelve strokes in a minute, is made to turn a wheel constantly one way, and the number of strokes is also increased to fifty or sixty in a minute. The machine is described by three figures annexed to the memoir, and is considered as ingenious. It is stated that it may easily be made to turn a mill to grind corn, or a wheel to raise coals.

It is related in the *Encyclopædia Britannica*, that Mr. Fitzgerald took out a patent for communicating a rotative motion from the steam-engine, but we believe this is a mistake. In the *Edinburgh Review* it is stated, that an atmospheric engine was employed at Hartley colliery, in Northumberland, as early as 1768, to draw coals out of a pit. It had a toothed sector on the end of the working beam, working into a trundle, which, by means of two pinions with ratchet-wheels, produced a rotative motion in the same direction, by both the ascending and descending stroke of the arch; and by shifting the ratchets, the motion could be reversed at pleasure. This engine had no fly-wheel, and went sluggishly and irregularly. Who the inventor was is not mentioned.

A patent was taken out in 1769 by a gentleman of the name of Stewart, for an engine which produced a rotative motion by a chain going round a pulley, and also round two barrels furnished with ratchet-wheels, with a weight suspended

to the free end of the chain, which served to continue the motion during the return of the engine. About the year 1778, Mr. Matthew Washbrough, of Bristol, also obtained a patent for communicating a rotative motion from the steam-engine, by a method which was virtually the same as that at Hartley; only he added a fly-wheel, which we believe was then, for the first time, employed in the steam-engine. Two or three of these engines were erected, one at his own works, for turning lathes, &c. and also one at Southampton, at Mr. Taylor's works, besides two or three for grinding corn; but, owing to the defective mode of communicating the motion, they were subject to such irregularities as rendered them of little use.

The crank, which is now the universal method of communicating the motion of the engine to machinery, was, we believe, first applied to an engine at Birmingham. This method of converting the reciprocating motion into a continuous rotatory motion, was by employing the great beam to work a crank or tram of wheelwork. As the real action of the engine was confined to its working stroke, it was soon found advantageous to equalize, as nearly as could be, the power of the working and returning strokes. For this purpose, the rod which extended from the beam to the crank, and connected the engine and the mill together, and which is called the connecting rod, was made equal in weight to half the power of the engine, being made of cast-iron of large dimensions; and when the weight was not in the rod, it was placed on the beam at that end.

Suppose that by this means the engine is made to exert an equal force to turn round the crank in the ascent and descent of the connecting rod, still it remains to find some force which shall continue the motion in the interval of its change from ascending to descending, and *vice versa*. To accomplish this, it is necessary to connect with the crank or wheel-work a very large and heavy fly, which shall accumulate in itself the whole force of the engine during its time of action; and therefore continue the motion, and urge forward the working machinery, while the steam-engine is going through its inactive period of changing the stroke. This will be the case, provided that the resistance exerted by the machine during the whole period of the working and returning stroke of the steam-engine, together with the friction of both, does not exceed the whole pressure exerted by the steam-engine during its periods of action upon the crank; and provided the momentum of the fly, arising from its weight and velocity, be sufficiently great; so that the resistance of the work, during the changing of the stroke of the steam-engine, will not make any very sensible diminution of the velocity of the fly. This is evidently possible and easy, for the fly may be made of any magnitude; and being exactly balanced round its axis, it will soon acquire any velocity consistent with the motion of the steam-engine. During the working stroke of the engine, it is uniformly accelerated; and by its acquired momentum, it produces the movement of the mill until the engine changes, and makes its returning stroke; but in doing this, its momentum is shared with the inert matter of the steam-engine, and consequently its velocity diminished, but not entirely taken away. The weight of the connecting rod, therefore, by pressing on the crank afresh during the returning stroke, increases the remaining velocity in the fly, by a quantity equal to the whole that it lost during the inactivity of the engine. This must be acknowledged to be a very important addition to the engine; and though sufficiently obvious, it is ingenious, and requires considerable skill and address to make it effective.

Mr. John Steed, in 1781, had a patent for applying the crank to a steam-engine; and in the same year, the abbé

Arnall Canon of Alais, in Languedoc, entertained a thought of the same kind, and proposed it for working lighters in the inland navigations, a scheme which is now successfully practised in America, and in this country. His brother, a major of engineers in the Austrian service, carried the proposal much farther, and applied it to manufactures; and the Aulic chamber of mines at Vienna patronized the project. (See Journal Encyclopédique, 1781.) But these schemes are long posterior to Mr. Hull's patent, or to Mr. Fitzgerald's proposals, and are even later than the erection of several machines driven by steam-engines by Messrs. Watt and Boulton.

When the more improved engines of Mr. Watt came into use, many persons tried to improve the atmospheric engines by adopting some of Mr. Watt's ideas: one of these was to employ valves to rise and fall perpendicularly into a conical seat, for the alternate admission of steam and cold water into the cylinder, instead of the sliding regulator and injection-cock. Mr. George Curr, who published his *Practical Coal-Viewer, or Engine-Builder's Companion*, in 1796, at Sheffield, gives drawings of such an engine, and tables for the proportions of all the parts, from which, as they contain information not given before, we have extracted the following particulars.

Mr. Curr's Table of Proportions for the Parts of Atmospheric Steam-Engines.

Cylinders.	Boilers.				Injection. The Cistern being 36 Feet above the Top of the Cylinder.				Scantling of the Working-Beams, 25 Feet long. Oak in a single Piece.		Iron Shanks for Piston	Beam-Centres.	Arch-head Chain.	Pressure on the Piston, at 7 lb. per square Inch.
Diameter in inches.	No of Boilers.	Diameter of the Boilers.	Diameter of the Feed-Pipe.	Diameter of the Steam-Pipe.	Water-way of Injection-Cock.	Square Hole for Jet.	Bore of Injection-Pump.	Bore of Injection-Pipe.	Square of the Middle.	Square at the Ends.	Square of one of the four Shanks for the Piston.	Diameter of the Beam-Gudgeons.	Diameter of the Pins for the Chains.	
25	1	Feet. 8 $\frac{1}{2}$	Inches. 2 $\frac{1}{2}$	Inches. 8	Inches. 2 $\frac{1}{2}$ by $\frac{7}{8}$	Inches. $\frac{1}{2}$	Inches. 3 $\frac{1}{2}$	Inches. 3 $\frac{1}{2}$	22 by 20	Inches. 19—15	Inches. 1 $\frac{1}{4}$	Inches. 3 $\frac{3}{4}$	Inches. 1 $\frac{1}{4}$	Pounds. 3436.12
30	1	10 $\frac{1}{2}$	3	9	3—1	$\frac{7}{8}$	4 $\frac{1}{2}$	3 $\frac{3}{4}$	24—22	21—16	1 $\frac{1}{2}$	4	1 $\frac{1}{2}$	4948.02
35	1	12 $\frac{1}{2}$	3	10	3 $\frac{1}{2}$ —1	1	5 $\frac{1}{2}$	3 $\frac{3}{4}$	26—23	22—17	1 $\frac{3}{4}$	4 $\frac{1}{4}$	1 $\frac{1}{2}$	6734.80
40	1	14	3 $\frac{1}{2}$	12	3 $\frac{1}{2}$ —1	1 $\frac{1}{2}$	6	4	28—25	24—18	2	4 $\frac{1}{2}$	1 $\frac{3}{4}$	8796.48
45	2	11	2 of 3	9	3 $\frac{3}{4}$ —1 $\frac{1}{2}$	1 $\frac{1}{2}$	6 $\frac{1}{2}$	4 $\frac{1}{2}$	30—27	26—19	2 $\frac{1}{2}$	4 $\frac{3}{4}$	1 $\frac{3}{4}$	11133.04
50	2	12 $\frac{1}{2}$	2—3	10	3 $\frac{1}{2}$ —1 $\frac{1}{2}$	1 $\frac{1}{2}$	7 $\frac{1}{2}$	4 $\frac{1}{2}$	32—29	28—21	2 $\frac{1}{2}$	5	2	13744.49
55	2	13 $\frac{1}{2}$	2—3 $\frac{1}{2}$	11	3 $\frac{3}{8}$ —1 $\frac{1}{2}$	1 $\frac{1}{2}$	8 $\frac{1}{2}$	4 $\frac{1}{2}$	33—30	29—22	2 $\frac{3}{4}$	5 $\frac{1}{2}$	2 of 1 $\frac{3}{4}$	16630.84
60	2	14 $\frac{1}{2}$	2—3 $\frac{1}{2}$	12	4 $\frac{1}{2}$ —1 $\frac{1}{2}$	1 $\frac{1}{2}$	9	5	35—32	31—24	3	6	2—1 $\frac{1}{4}$	19798.08
65	2	16	2—3 $\frac{3}{4}$	12 $\frac{1}{2}$	4 $\frac{1}{2}$ —1 $\frac{1}{2}$	1 $\frac{1}{2}$	9 $\frac{1}{2}$	5 $\frac{1}{2}$	36—33	32—25	3 $\frac{1}{2}$	6 $\frac{1}{2}$	2—1 $\frac{1}{2}$	23228.20
70	2	17	2—4	13	4 $\frac{1}{2}$ —1 $\frac{1}{2}$	1 $\frac{1}{2}$	10 $\frac{1}{2}$	5 $\frac{1}{2}$	38—35	33—26	3 $\frac{3}{4}$	6 $\frac{3}{4}$	2—2	26939.22

In all these engines, he supposes the length of the stroke to be nine feet, and that they work 8 1/2 feet stroke in common work.

In 1793, Mr. Francis Thompson had a patent for making the atmospheric engine work a double stroke, for the convenience of turning machinery by a crank; this he effected by employing two cylinders, one inverted over the other, and the piston of both connected by one rod, which passed through the bottom, or rather the top of the inverted cylinder, and was connected with the beam: by this means the cylinder acted alternately to make an up or down stroke. This never came into use, for the engine was as complicated as Mr. Watt's, without any of his advantages.

Mr. Watt's Steam-Engine.—The principle of this valuable invention will be best explained by a statement of the manner in which it originated, and the steps by which it attained its present degree of perfection.

Mr. James Watt was, in 1763, a maker of mathematical instruments at Glasgow, and being a man of a truly philosophical mind, and well conversant with all branches of science, he was in habits of associating with the most celebrated scientific men at that time in Scotland, particularly with Dr. Black, Dr. Roebuck, and Dr. Robison, then a young philosopher. About this time he undertook to repair a working model of a steam-engine belonging to the university of Glasgow, and during this employment, observed the great loss of steam from the condensation of the cold surface of the cylinder, which we have before explained in Mr. Smeaton's investigations, though the latter were not made till after Mr. Watt's. He observed that a great quantity of heat is contained in a very minute quantity of water, in the form of elastic steam; for when a quantity

of water is heated several degrees above the boiling point in a close digester, if a hole be opened, the steam rushes out with great violence, and in three or four seconds, the heat of the remaining water is reduced to the boiling heat. If the steam be condensed, the whole of it will afford only a few drops of water; yet this small quantity, in the state of steam, carried off with it all the excess of heat from the water of the digester. Mr. Watt reasoned, that if so great a quantity of heat is contained in a certain quantity of steam, the economical use of the steam was a matter of the first importance in the improvement of the engine, more than the construction of the furnace, which had been the chief object of former efforts to improve the engine, the improvement of the application of the steam having been much neglected after it was first settled by Beighton.

The cylinder of the little model was heated when the steam was in it, so that it could not be touched by the hand; but before a vacuum could be made, it required to be cooled by the injection, and was then to be heated again by the re-entrance of the steam: this, he saw, could not happen, unless the heat was abstracted from the steam, which must occasion the condensation and waste of a considerable portion. His first enquiry was, what portion of the steam was thus wasted; but so very few experiments had been made, even upon the most essential part of the subject, that the real bulk of water, when converted into steam of a given heat, remained unknown, until he determined it by new experiments in the year 1764. The opinions which had been entertained concerning its bulk before that time were much beyond the truth, and could by no means be deduced from the very inaccurate experiments which were said to have been made.

Thus furnished with data, he was enabled to ascertain that the loss of steam, in alternately heating and cooling the cylinder, was not less than three or four times as much as would fill the cylinder and work the engine. The boiling of water in an exhausted receiver at low heats, which had been discovered, we believe, by M. Coulomb, was about this time communicated to Mr. Watt; but it was neither known what these heats were, nor what progression they observed under various pressures, before he made his experiments on that subject. These experiments pointed out another defect of the common steam-engine, *viz.* that the injection-water thrown into the cylinder to condense the steam becoming hot, and being in a vessel exhausted of air, it produces a steam or vapour, which in part refills the pressure of the atmosphere upon the piston, and lessens the power of the engine: this might be remedied by throwing in as much water as would cool the whole vessel below the point at which water boils in vacuo; but then it would increase the first-mentioned inconvenience, which is the destruction of steam that unavoidably happens upon attempting to fill a cold cylinder with that fluid. Others, who had constructed steam-engines, found, that as they made their exhaustion more perfect by making the cylinder colder, they increased the consumption of steam in a greater proportion than they gained power. Though it appears they were ignorant of the cause, they were so sensible of the effect, that they contented themselves with causing the engine to raise a load equal to seven pounds upon the square inch of the area of the piston; whereas the pressure of the atmosphere would have raised much more, if the cylinder had been perfectly exhausted.

Mr. Watt's first attempt at the improvement of the engine was by employing a wooden cylinder, which would transmit the heat more slowly: this had some effect, but did not answer in other respects, and he was obliged to abandon it, as well as Mr. Brindley, who had before tried the same thing. He then cased his metal cylinders in a wooden case with light wood-ashes: by this, and using no more injection than was absolutely necessary for the condensation, he reduced the waste almost one-half. But by using so small a quantity of cold water, the inside of the cylinder was hardly brought below the boiling temperature, and there consequently remained in it a steam of very considerable elasticity, which robbed the engine of a proportionable part of the atmospheric pressure.

It was not until the next year (1765) that Mr. Watt made his great invention of performing the condensation in a separate vessel from the cylinder. He conceived, that if a vessel, which he afterwards called the condenser, was made to communicate with the cylinder by a pipe, and filled with steam at the same time, an injection being thrown into the latter vessel would condense the steam therein, and cause a vacuum. Under these circumstances, the elasticity of the steam in the cylinder would cause it to rush into the vessel to restore the equilibrium; but this steam being condensed immediately it entered the vessel by the continuance of the injection, the vacuum would still remain, and draw off the remaining steam from the cylinder until none was left. Here then was the vacuum in the cylinder produced, without any necessity for diminishing the temperature below the boiling point. Having thus obtained the vacuum to cause the descent of the piston, the subsequent re-ascend could be obtained by cutting off the communication between the cylinder and the condenser, and admitting into the former a fresh supply of steam from the boiler; but it was not necessary to admit any fresh steam from the boiler to the condenser, as the vacuum produced therein still continued, and it would be ready to receive

and condense the steam from the cylinder, as soon as the piston arrived at the top of it, ready to make another stroke.

The first difficulty which opposed itself to this beautiful chain of reasoning was, how to continue the action, and prevent the separate condensing vessel from filling with the injection-water, and also how to get rid of the air. To snuff by blowing steam into the vessel, in the manner of the former engine, would have caused him as great a waste of steam from condensation, as he would save by all his discovery. He then thought of condensing without injection, simply by the application of cold water to the outside of the condenser, on Savery's first plan; and to get rid of the small quantity of water produced by the condensation of the steam, he intended to carry a pipe down from the condenser to a depth of 34 feet, from the end of which the water would run off by its gravity. But the air which is carried over by the steam would also accumulate by degrees, and could not be so easily evacuated; a small pump must then be applied to draw it off, and keep the condenser empty.

Mr. Watt at the same time conceived, that it would be very advantageous to employ the pressure or expansive force of the steam to actuate the piston in its descent, instead of the pressure of the atmosphere, as it would be more manageable than the other in its intensity. Thus was the whole discovery made in a day; and it only remained to invent the details of the mechanism to carry it into effect, and to establish by experiment the requisite proportions of the parts.

Mr. Watt's first experiment on these new ideas was to try the effect of the separate condenser; but before he had made the apparatus for the experiment, he resolved to extract the condensed water from his condenser by means of the same pump which should draw off the air, as this method would be applicable in all situations.

The first apparatus was a cylindrical vessel, fitted with a piston, which could be drawn up in it to exhaust the air therefrom. This vessel was made to communicate, by means of a long pipe half an inch in diameter, with the cylinder of the engine, which was two inches in diameter, and ten inches long. The pipe had a stop-cock, to cut off the communication at pleasure; and the cylindrical vessel, which was made of thin tin-plate, was immersed in cold water. The piston of the cylindrical vessel being pressed to the bottom to displace the contained air, was then drawn up to leave a vacuum space, and the cylinder of the engine, having its piston at the top, was filled with steam. The cock in the communicating pipe being then opened, the piston descended with a velocity, which shewed that the vacuum in the cylinder was almost perfect; and he found, that when he used water in the boiler purged of air by long boiling, nothing that was very sensibly inferior to the pressure of the atmosphere on the piston could hinder it from coming quite down to the bottom of the cylinder. This alone was gaining a great deal; for in most engines, the remaining elasticity of the steam arising from the heated injection-water was not less than one eighth of the atmospheric pressure, and therefore took away one-eighth of the power of the engine.

Mr. Watt was so much occupied in other business, that it took him much time to complete his machine, and bring the whole to bear, so that he did not apply for his first patent until 1768, which bears date 5th Jan. 1769, and is for his method of lessening the consumption of steam and fuel in fire-engines. The specification contains the following principles.

"First. That the vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time that the engine is at work, be kept as hot as the steam that enters it; first, by enclosing it in a case of wood, or any other material that transmits heat slowly; secondly, by surrounding it with steam, or other heated bodies; and thirdly, by suffering neither water, nor any other substance colder than steam, to enter or touch it during that time.

"Secondly. In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them. These vessels I call condensers; and while the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by applications of water, or other cold bodies.

"Thirdly. Whatever air, or other elastic vapour, is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly. I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by the force of steam only, by discharging the steam into the open air after it has done its office.

N. B. This should not be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessels having an open communication with it.

"Fifthly. Where motions round an axis are required, I make the steam-vessels in form of hollow rings, or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles, like the wheels of water-mills. Within them are placed a number of valves, which suffer bodies to go round the channels in one direction only. In these steam-vessels are placed weights, so fitted to them as entirely to fill up a part or portion of their channels, yet rendered capable of moving freely in them by the means hereinafter mentioned or specified. When the steam is admitted into these engines, between the weights and the valves, it acts equally on both, so as to raise the weights to one side of the wheel, and by the re-action on the valves, successively to give a circular motion to the wheel; the valves opening in the direction in which the weights are pressed, but not in the contrary one, as the steam-vessel which moves round it is supplied with steam from the boiler, and that which has performed its office may either be discharged by means of condensers, or into the open air.

"Sixthly. I intend, in some cases, to apply a degree of cold, not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

"Lastly. Instead of using water to render the piston or other parts of the engines air and steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state."

Soon after his patent, Mr. Watt became associated with Dr. Roebuck, who established the Carron iron-works. They proposed establishing an extensive manufactory for such engines under the patent; and Mr. Watt began his first real engine of 18 inches cylinder, at Kinnell, near

Borrowstowness. This was a sort of experimental engine, and was successively altered and improved till it was brought to considerable perfection. In the details of its construction, the greatest difficulty of all was in the packing of the piston, so as to be steam-tight; because Mr. Watt's principle did not admit of water being kept upon the piston to prevent the leakage, as in the old engines. He found great difficulties in procuring a cylinder sufficiently accurate, until a new method was introduced at Burham foundery, by Mr. John Wilkinson. In the old method of boring, the instrument which performs the part of cutting the metal was guided in its progress only by the incorrect form given to the cylinder by the moulder; and though it insured that every part of the cylinder should be circular, it gave no certainty that the cylinder would be straight. This was quite sufficient for the old engines, but Mr. Watt's engines required greater precision. Wilkinson's machine, which is described in our article CYLINDER, insures all the accuracy the subject is capable of; and if the cylinder should be cast ever so crooked, the machine will bore it straight and true.

Dr. Roebuck becoming embarrassed, from the failure of his vast undertaking in the Borrowstowness coal and salt works, was unable to prosecute the manufactory of steam-engines, and, in 1774, disposed of his interest in Mr. Watt's patent to Mr. Matthew Boulton, whose establishment at Soho, near Birmingham, was then the most complete in England, and conducted with the most spirit. A portion of the works was allotted to Mr. Watt, who erected a foundery, and the necessary works to carry his invention into effect, on a grand scale.

In consequence of the great loss of time, and the enormous expence necessary for bringing the engine to perfection, Mr. Watt was not able to produce any large engines, as specimens of his invention, until 1774; and found, from the difficulty of introducing them, that the term of his patent was likely to pass away before he should be reimbursed: he, therefore, applied to parliament for a prolongation of his term, which was granted for 21 years, by an act passed in 1775. With this encouragement, and with the advantage of Mr. Boulton's assistance in systematizing the manufacture of the parts, Mr. Watt soon produced many capital engines, which were erected in Staffordshire, Shropshire, and Warwickshire, and a small one at Stratford near London. He found it was necessary to admit a small jet of injection into the condenser, and to employ an air-pump of sufficient dimensions to extract both the condensed steam and injection-water, as well as the air; for the condensation, by the application of external cold, was not sufficiently rapid, and the engine was so much improved as to afford amply for the power requisite to work the air-pump.

The condensing of the steam, by injection into the eduction-pipe, was an idea as early as the other kinds of condensers, and was tried in the very first engine built at Kinnell; but the other imperfections of that machine, owing to its leaks and bad workmanship, made a bad vacuum; and this being attributed to the air which came in with the injection-water, Mr. Watt diffused the injection into the condenser, until the size and expence of the tubulated condenser for large engines, made him resolve to sacrifice a part of the power of the engine to convenience, and to employ larger air-pumps. In an engine at Bedworth, three air-pumps were used, two below, which were side by side, and worked by chains from each side of the beam, and a third above these two, and between them in the middle: this third one received the hot water lifted up by the other two; and by lessening the surface exposed to the pressure of the atmosphere, extracted the water

with greater ease. In 1778 he only employed two air-pumps for the largest engines, one being double the area of the other, and in succeeding engines used only one, as at present, which is the air-pump of Smeaton.

A sketch of one of these first engines is given in *Plate IV. Steam-Engine, fig. 4.* The cylinder, and great beam, with its arch-heads and the pumps, stood in the same position as the former engines; but the cylinder, A, was smaller in proportion to the load than those before used, as it was generally loaded to $12\frac{1}{2}$ pounds on the square inch. The cylinder was very accurately bored withinside, to make it straight and cylindrical, and externally it was surrounded by a second cylinder, or jacket B B, leaving a small space, G, all round between the bored or internal cylinder, and the outer jacket B.

This space, G, communicated by a large pipe, F, with the boiler, and always remained full of steam, so as to keep the cylinder, A, at the same heat with the steam, and thereby prevent any condensation within it, which would have been a much greater loss than an equal condensation from the external surface of the jacket B. The jacket, B, was furnished with a lid, C, which had a hole in the centre for the piston-rod, a, to pass through. The rod was made truly cylindrical, so that the hole could be kept steam-tight by a collar of oakum screwed round it at E. The inner cylinder, A, had a close bottom, and the jacket, B, joined to the same, the cylinder being fitted with the piston H H, as usual; but the top of the internal cylinder, A, did not reach quite up to the lid of the jacket B, or outer cylinder; by which means the steam had always free access to the top of the piston, H, from the space, G, between the cylinders, and consequently from the boilers through F. At the bottom part of the inner cylinder there were two regulating valves, O and K, one of which, O, either admitted the steam to pass from the interstice, G, between the jacket and the cylinder, through a passage, I, into the space of the interior cylinder below the piston, or shut out the steam from that space at pleasure: the other valve, K, opened or shut the end of the eduction-pipe M, which conducted to the condenser L. The condenser, L, was a close vessel, made of thin metal, and furnished with an air-pump N. The air-pump had valves, and a bucket, b, for exhausting the air, and drawing off the water which was produced by the condensation of the steam, along with the air which is extricated from the water in boiling, and rises with the steam. The air-pump was constructed nearly the same as a common pump, except that it had a lid or cover on the top of the barrel, to keep the pressure of the atmosphere from bearing constantly upon the bucket. The rod, d, of the bucket passed through a stuffing-box in the lid, and was suspended by a chain from the great working beam of the engine. The condenser L, together with the air-pump N, were placed in a large cistern of cold water X, situated generally under the floor of the engine-house, between the cylinder and the wall on which the beam rested, and supplied constantly with fresh cold water from a small pump worked by the engine, or the cistern was placed outside of the wall, between the wall and the pit of the pump.

The action of this engine is as follows: suppose steam from the boiler to enter at F, and fill the space, G, between the jacket and the cylinder, and also the upper part of the cylinder above the piston. The condenser, L, is exhausted of its air, by opening both valves, O and K, in the bottom of the cylinder, and allowing the steam from the space, G, to blow through it, and through the valves of the air-pump: both valves are then shut, and the external cold condenses it so as to leave a vacuum in the condenser, whilst the cylinder, A, is all the while full of steam, from the space G, both above and be-

low the piston H: the steam-valve, O, being shut, cuts off all communication with the under side of the piston from the steam in G, or in the boiler, and at the same time the exhausting-valve, K, from the condenser is opened, when the steam rushes from the space of the cylinder A, below the piston, through the eduction-pipe M, into the vacuum of the condenser, with great violence, till it comes in contact with the cold sides of the condenser L, which is made of thin metal, and immersed in cold water. Under these circumstances the steam is immediately deprived of its heat, and reduced into water; more steam immediately rushes in from the cylinder, until it is exhausted, and makes a vacuum beneath the piston H. The steam which is above the piston ceasing to be counteracted by the steam which was below it, presses between the top of the piston and the bottom of the lid, C, with its whole elastic force, and causes the piston to descend to the bottom of the cylinder, carrying along with it the beam, and raising the pump-buckets at the other end. The exhausting-valve, K, is then shut, and the steam-valve, O, opened, which, allowing the steam to enter below the piston, leaves it at liberty to rise; in which case, the superior weight of the pump-rods raises the piston to the top of the cylinder, ready to commence another stroke.

The advantages that arise from this construction are: 1st. The cylinder, being surrounded with the steam from the boiler, is always kept uniformly as hot as the steam itself, and is, therefore, incapable of destroying any part of the steam which should fill it, as the common engines do. 2dly. The condenser being kept always as cold as water can be procured, and colder than the point at which it boils in vacuo, the steam is perfectly condensed, and does not oppose the descent of the piston; it is, therefore, forced down by the full power of the steam from the boiler, which is somewhat greater than that of the atmosphere. 3dly. The elasticity of the steam being employed to press down the piston, instead of the pressure of the atmosphere, the air does not enter the cylinder, or cool its interior surface; and the engine is not confined, as in the former engine, to work with its whole force, but it is only to administer steam of a proper elasticity, and we can vary the force of the engine very considerably, without losing any more fuel than that for which we obtain an effect.

When an engine of the old form is to be erected, the engineer must make an accurate estimate of the work to be performed, and must proportion his engine accordingly. He must be careful that it be fully able to execute its task; but its power must not exceed its load in any extravagant degree. This would produce a motion which is too rapid, and which, being alternately in opposite directions, would occasion jolts, which no building or machinery could withstand. Many engines have been shattered by the pump's drawing air, or a pump-rod breaking; by which accidents, the steam-piston descends with such force and rapidity, that every thing must give way. But in most operations of mining, the task of the engine increases, and it must be so constructed, at first, as to be able to bear this addition. It is very difficult to manage a common engine when it is much superior to its task: the only mode is, as we have described, by the supply of a scanty injection; but the easiest way is to work the engine almost full loaded, and that only during a few hours each day, allowing the pit-water to accumulate during its repose. This increases the first cost of the erection, and wastes fuel; the miners are also much incommoded with water during the inaction of the engine. Mr. Watt's engine can, at all times, be exactly fitted, during the working stroke, to the load of work that then happens to be on it: it is only necessary to administer steam of a proper elasticity. At the first erection of the

engine, it may be calculated equal to twice its task, supposing that the steam admitted above the piston is to be three or four pounds *per* square inch more elastic than the atmosphere; but when the engine is first set to work, it may be made to act with a small portion of its force, by using weaker steam; for when once the ebullition in the boiler is fairly commenced, and the whole air is expelled from all parts of the apparatus, it is evident that, by damping the fire, steam of half this elasticity may be continually supplied, and the water will continue boiling, although its temperature does not exceed 185° of Fahrenheit's thermometer. This appears, by inspecting our first table of vaporous elasticity.

The method now proposed has one inconvenience; for, while the steam is weaker than the atmosphere, there is an external force tending to squeeze in the sides and bottom of the boiler, which could not be resisted in a large boiler, if the difference was considerable, and common air would rush in through every crevice of the joints of the engine. The regulation of the velocity of the engine may be produced by diminishing the passage for the steam into and out of the cylinder; for this purpose, the exhaustion-valve K, by which the steam passes away from the cylinder, may be so constructed, that its mechanism will lift it more or less high from the conical seat in which it is lodged, and consequently the passage can be enlarged or contracted at pleasure, by the distance to which the valve is drawn up. The degree of opening given to the exhaustion-valve would determine the rate at which the steam would flow off from the lower part of the cylinder to the condenser, and consequently the velocity of the descent of the piston; also the degree of opening of the other, or steam-valve, O, would determine the rate of the ascent of the piston, by regulating the rate at which the steam could pass from the boiler into the lower part of the cylinder.

But to save the trouble of making the adjustment for the degree of opening of the working-valves, it is better to place a separate valve in some part of the steam-pipe F, which brings the steam from the boiler to the jacket of the cylinder; then if this valve, which is called the throttle-valve, and is solely for the purpose of regulation, be partially closed, so that it will not admit steam into the jacket as fast as the descent of the piston makes room for it in the cylinder, it is evident that the steam in the top of the cylinder, and in the space of the jacket, must expand itself to fill a greater space, and thereby become more rare than before, and press upon the piston with less force. And this mode of regulation, by diminishing the quantity of the supply of steam, rather than diminishing its elasticity in the boiler, has this advantage, that a very considerable increase of the load of the engine cannot stop its motion, although it may retard it, because the closing of the throttle-valve only diminishes the velocity of the motion, not the force which the engine is capable of exerting when moving under a still less velocity. Suppose the load is so increased as to make the engine move very slowly, the steam will flow through the valve into the jacket and top of the cylinder faster than the descent of the piston will make room for it, and in consequence it will accumulate, until it has acquired the same pressure as within the boiler, or a sufficient pressure to overcome the resistance to the piston, and make it descend.

The form of the engine represented in *fig. 4.* was that which Mr. Watt first employed in his single engines for pumping; and, in some cases, where atmospheric engines were altered to this plan, the old cylinder, being inverted, served for the jacket, or external cylinder, the new cylinder being little more than half the area of the old one. He afterwards adopted another form for the arrangement of the parts, in which the steam for the supply of the cylinder does not

pass through the jacket, but enters from the steam-pipe through a valve immediately into the top of the cylinder; and though the jacket has a communication with the boiler, the steam admitted within it is only for the purpose of keeping up the heat, and preventing any condensation of the steam within the cylinder. In this way the jacket becomes less essential to the engine; and about the year 1778, Messrs. Boulton and Watt began to make the jackets of wrought-iron plate, about 1½ inch from the cylinder all round; and, in some cases, they laid the jacket aside, but found this an ill-judged economy, and returned to it again, as they perceived that it made a difference in the fuel.

This engine is represented in *Plate IV. fig. 5.* The cylinder, A A, like the former, is closed at top by the lid or cover C; but this lid is screwed to the top flanch of the cylinder itself, instead of the top of the jacket, which may be omitted or not in this form, because the current of steam from the boiler, for the supply of the cylinder, does not flow through it, as in the former engine. The steam is brought from the boiler to the cylinder by the pipe F, which appears like a circle, being cut across in the direction of its length: *f* is the regulating or throttle-valve in that pipe, and *d* the communicating passage into the top of the cylinder, immediately beneath the valve, so that through this the steam has always entry into the top of the cylinder to press upon the piston, in such quantity as the opening of the regulating-valve, *f*, will allow. W is the steam-pipe, which descends to the bottom of the cylinder, for the purpose of establishing a communication between the top and bottom of it, when the piston is to ascend; and O is the steam-valve, which opens or shuts that communication at pleasure. F is the exhausting-valve, which being opened when the steam-valve, O, is shut, allows the steam to pass off to the condenser, which may be considered as the same which we have before described.

Suppose the piston at the top of its cylinder, and all the parts (except the eduction-pipe M, and condenser, which are vacuum) full of steam; if the valve O be shut, the exhausting-valve K, being opened, will permit the steam contained in the lower part of the cylinder to pass by its elasticity, and rush into the vacuum of the eduction-pipe and condenser; and being there condensed, the rest will follow till none remains: then the steam, flowing through the throttle-valve, and passage *d*, into the top of the cylinder, presses down the piston into the vacuum cylinder, until it arrives at the bottom; the exhausting-valve, K, is then shut, and at the same time the steam-valve, O, is opened by the plug-frame: this suffers the steam from the boiler to rush into and occupy that small portion of the bottom of the cylinder beneath the piston, which being filled with steam of an equal density to that above it, there will be an equal pressure on both sides of the piston; and the opening of the valve, O, having made a free communication between the top and bottom of the cylinder, the piston is at full liberty to rise by the action of its counter-weight, until it arrives at the top of the cylinder, and then the steam-valve, O, is shut, and the exhausting-valve, K, opened, to make another stroke, as before.

The sketch in *fig. 2.* was taken from an engine Messrs. Boulton and Watt erected at Hull, in 1779; and this, with some slight variations in the manner of its action, which we shall afterwards describe, is the present standard engine for pumping water: the variation is, that the regulating-valve, F, is made to open and shut at every stroke, and for regulation, another valve is applied in the steam-pipe just before it arrives at F.

In the two engines which we have described, the piston descends in consequence of the pressure of the steam being

made to act upon it whilst there is a vacuum beneath ; and the ascent is made, when the piston is placed in equilibrio, by an open communication being made between the upper and lower parts of the cylinder ; and this will always be an exact equilibrium, not imperfect, as in the old engine, where the varying pressure of the steam and of the atmosphere always renders the circumstances in which the piston rises uncertain.

It is evident that the ascent of the piston may be as well performed in vacuo, provided the vacuum is made at the same time both above and below the piston. This form of the engine is represented in *fig. 3*, in which, as the same letters of reference are used, it is needless to repeat the description of the cylinder and piston. F is the valve which admits the steam to the top of the cylinder, to press upon the piston : this valve is shut when the engine makes its return or up-stroke. K is the exhaustion-valve, placed close beneath the steam-valve F, instead of being at the bottom of the pipe W, which descends to the condenser, and gives off a branch, I, to the bottom of the cylinder : by this pipe the steam is always drawn off from the bottom of the cylinder, to keep a constant vacuum therein. Suppose the exhausting-valve, K, open, the steam in the top of the cylinder will also pass off to the condenser through the pipe W, and leave a vacuum in the whole cylinder : in this case the piston rises freely by the counter-weight to the top of the cylinder ; and being arrived there, the exhausting-valve, K, is shut, and the steam-valve, F, opened. The steam from the boiler entering into the top of the cylinder, and pressing between the lid and the top of the piston, presses down the latter to the bottom of the cylinder, where being arrived, the steam-valve, F, is shut, to prevent the farther admission of steam from the boiler ; and at the same instant, the exhausting-valve, K, being opened, the steam from the top of the cylinder passes off to the condenser, and this makes a vacuum above the piston, the same as was before made beneath it : in consequence, the piston is left at full liberty to rise by the action of the counter-weight, until it arrives at the top : the exhausting-valve, K, is then shut, and the steam-valve, F, opened, to make a fresh descent. The advantage of this construction is, that the whole time of the ascent of the piston is allowed for making the condensation ; but this is found of little importance in practice, because the vacuum takes place almost instantaneously, when the exhausting-valve is opened, to allow the steam to pass off to the condenser.

Mr. Watt's Expansion-Engine.—This was a most important improvement, of which Mr. Watt had the first idea in 1769, but did not fully put it in practice until 1778. It consists in shutting off the farther entrance of steam from the boiler, when the piston has been pressed down in the cylinder for a certain proportion of its total descent, and then leaving the remainder of the descent to be accomplished by the expansive force of that steam which is already introduced into the cylinder. This gives the means of regulating the acting force of the engine, because the pins of the plug-frame can be placed in such a manner, as that the steam-valve shall be shut when the piston has descended one-half, one-third, one-fourth, or any other proportion ; and so far the cylinder will be occupied with steam of the same elasticity as that in the boiler, which is usually about the same as the atmosphere. In order to press the piston farther down, the steam must expand ; and though its elasticity will diminish, it will be enough to complete the stroke. It is plain that this can be done in any degree at pleasure, as the adjustment of the pins in the plug-frame can

be varied in an instant ; and according as the engine requires more or less power, to allow the steam to act with its full force upon the piston for a greater or less portion of its total descent. If this method of working an engine had no other advantage than the regulation of the power, it would not effect the end better than the throttle-valve ; but by the expansive principle a great saving of steam is made. We have before observed, in describing the action of Newcomen's engine, that the motion of the piston is accelerated in its descent by the continued action of the pressure of the atmosphere whilst the load is constant, or even greatest at the first, considering the vis inertia. Mr. Watt's engine is the same, but in a less degree, when it has a throttle-valve, because the steam cannot then come to the piston, except in a limited quantity ; but when the top of the cylinder is open to the boiler, or the throttle-valve fully open, the effect is the same as if the atmospheric air had free entrance into the top of the cylinder. Now by stopping the further entrance of the steam at a certain portion of the descent, the piston can be made to descend with an uniform velocity, by the expenditure of only a portion of that quantity of steam which would be required, if steam of its full density was employed to press it down to the bottom with an accelerated velocity.

But when the steam is shut off at a portion of the descent, the pressure on the piston is continually diminishing as the steam becomes more and more rare ; and, consequently, the accelerating force which works the engine diminishes. The motion of the descent, therefore, will no longer be uniformly accelerated ; it will approach much faster to uniformity ; or it may even be retarded ; because, although the pressure on the piston at the beginning of the stroke may exceed the resistance of the load, yet when the piston is near the bottom, diminution of the pressure may occasion the resistance to exceed the pressure ; in this case the motion can only be continued by the momentum of the moving parts. Whatever may be the law by which the pressure on the piston varies, it is possible to contrive the connecting machinery in such a way, that the chains or rods at the outer end of the beam shall continually exert the same pressure to lift the pump-rods, or that the machinery shall vary its force according to any law which is found most convenient. This may be done on the same principle that the watch-maker, by the form of the fulcrum, transmits an equal pressure to the wheel-work, from a very unequal action of the main-spring. In like manner, by making the communication from the piston-rod to the pump-rod by means of chains, which wind upon arch-heads, formed to portions of a proper spiral instead of a circle, the force of the piston upon the beam and pump-rods can be regulated at pleasure, so as to produce an uniform effect.

This was the subject of Mr. Watt's patent, March 12, 1782, for certain improvements upon steam-engines, and certain new pieces of mechanism to be added to them. The specification of this patent, which is lodged in the Rolls chapel, states the invention to consist in shutting off the steam at a portion of the descent, as we have described, and applying and combining levers, or other contrivances, so that the unequal or decreasing action of the steam upon the piston shall produce an uniform effect in raising the water in the pump-barrels.

The action of the expansion of the steam on the piston is thus explained. Suppose the whole descent of the piston decimally divided, viz. into ten parts, and each subdivided, the varying pressure of the expanding steam on the surface of the piston at each division will be according to the following

table, which we have made out from the information given in Mr. Watt's specification, and which is on the supposition that the cylinder is eight feet long, or an eight-feet stroke, and that the steam is shut off at one-fourth of the descent, or at two feet from the top: but the same law will hold gene-

rally as to these particulars. The pressure of the steam in the boiler is supposed to be equal to that of the atmosphere, or 14 lbs. *per* square inch, and the load of water in the pumps equal to 10 lbs. *per* square inch of the piston's surface.

	Portions of the Descent from the Top of the Cylinder		Proportion of the Pressure of the Steam on the Piston to the whole Pressure of 14 lbs. <i>per</i> square Inch.	
	.05			
	.1			
	.15	Full supply of steam from the boiler		} This is the full pressure of 14 lbs. <i>per</i> inch, before the supply of steam is shut off.
	.2			
One-fourth, or	.25			
	.3		0.83	
	.35		0.714	
	.4		0.625	
	.45		0.555	
One-half, or				} Or half the original pressure ; viz. 7½ lbs. <i>per</i> square inch.
	.55		0.454	
	.6	Supply of steam cut off, and the de-	0.417	
	.65	scend is produced by the expansion	0.385	
	.7	only	0.375	
Three-fourths,	.75		0.333	} Or one-third the original pressure ; viz. 4½ lbs. <i>per</i> square inch.
	.8		0.312	
	.85		0.294	
	.9		0.277	
	.95		0.262	
Bottom of cylinder	1.		0.25	} Or one-fourth the original pressure ; viz. 3½ lbs. <i>per</i> square inch.

11.583

Upon this the specification remarks, that the sum of all the varying powers is greater than fifty-seven hundredth parts of the original power multiplied by the length of the cylinder, whereby only one-fourth of the steam necessary to fill the cylinder is employed, and the effect is more than half that which would have been produced by the cylinder full of steam. Thus the sum of all the numbers which express the action of the steam, taken at twenty different places in the descent, is 11.583; whilst the whole pressure, represented by 1, and taken likewise at twenty different places, will be 20; it is therefore $\frac{11.583}{20}$, or $\frac{11583}{20000}$.

Dr. Robison's investigation of Mr. Watt's expansion-engine is as follows: Let $CrIR$ (*fig. 6.*) represent a section of the cylinder of a steam-engine, and HH the surface of its piston. Let us suppose that the steam was admitted, while HH was in contact with Cr ; and that as soon as the steam had pressed it down to the situation EF , the steam-cock is shut. The steam, by expanding itself, will continue to press it down; and as the steam expands, its pressure diminishes. We may express its pressure (exerted all the while the piston moves from the situation Cr to the situation EF) by the length of the line EF . If we suppose the elasticity of the steam proportional to its density, as is nearly the case with air, we may express the pressure on the piston in any other position, such as ML or IR , by $M/$ and $I/$, the ordinates of a rectangular hyperbola F/c ; of which CE , Cr , are the asymptotes, and C the centre. The accumulated pressure, during the motion of the piston from EF to IR , will be expressed by the area EF/cIE ; and the pressure during the whole motion, by the area

CrF/cIC . Now it is well known, that the area EF/cIE is equal to $CrFE$, multiplied by the hyperbolic logarithm of $\frac{CI}{CE} = L \cdot \frac{CI}{CE}$; and the whole area CrF/cIC is $= CrFE \times (1 + L \cdot \frac{CI}{E})$.

Thus, let the diameter of the piston be 24 inches, and the pressure of the atmosphere on a square inch be 14 pounds; the pressure on the piston is 6333 pounds. Let the whole stroke be six feet, and let the steam be stopped when the piston has descended 18 inches, or 1.5 foot. The hyperbolic logarithm of $\frac{6}{1.5}$ is 1.3862943; therefore, the accumulated pressure CrF/cIC is $= 6333 \times 2.3862943 = 15114$ pounds.

As few professional engineers are possessed of a table of hyperbolic logarithms, while tables of common logarithms are or should be in the hands of every person who is much engaged in mechanical calculations, let the following method be practised: Take the common logarithm of $\frac{CI}{CE}$, and multiply it by 2.3026, the product is the hyperbolic logarithm of $\frac{CI}{CE}$. The accumulated pressure, while the piston moves from Cr to EF , is 6333×1 , or simply 6333 pounds; therefore, the steam, while it expands into the whole cylinder, adds a pressure of 8781 pounds.

Suppose that the steam had been freely admitted during the whole descent of the piston, the accumulated pressure would have been 6333×4 , or 25,332 pounds. Here Mr. Watt observed a remarkable result. The steam expended, in this case, would have been four times greater than when it was stopped at one-fourth, and yet the accumulated pressure is not twice as great, being nearly five-thirds. One-fourth of the steam performs nearly three-fifths of the work; and an equal quantity performs more than twice as much work, when thus admitted, during one-fourth of the motion.

This information is curious and important, and the advantage of this method of working a steam-engine increases in proportion as the steam is sooner stopped; but the increase is not great, after the steam is rarefied four times, as the curve then approaches near to the axis, and small additions are made to the area. The expence of such great cylinders is considerable, and may sometimes compensate this advantage.

Let the Steam be stopped at	Its Performance is multiplied
$\frac{1}{4}$	1.7
$\frac{1}{3}$	2.1
$\frac{1}{2}$	2.4
$\frac{2}{3}$	2.6
$\frac{3}{4}$	2.8
$\frac{4}{5}$	3.0
$\frac{5}{6}$	3.2

The advantages of the expansive method of working an engine are more fully obtained, when steam of an elastic pressure considerably greater than the atmosphere is employed. The second table of expansion shews, that the increase of the force of steam, heated much above the boiling point, is very great by a small increase of heat. For instance, at 212° , the steam is equal to the atmosphere: by only increasing the heat 40° , viz. to about 252° , we obtain a double pressure, or two atmospheres; and the farther increase of 30° , viz. to about 282° , makes an additional force, which renders it equal to three atmospheres. Again, 24° higher, or about 306° , makes the steam equal to four atmospheres; and if it were practicable to go much farther, probably the same law would hold. Now it follows as a consequence, that if such small accessions of heat produce so rapid an increase of the expansive force, small abstractions of heat from highly elastic steam will also reduce its elasticity in an equal degree, so that steam highly heated is more readily diminished in bulk by the application of cold than weaker steam; that is, it can be more readily reduced in its pressure to any certain proportion of the pressure it had before. But if we would take away all its pressure, and leave a vacuum, we must apply a sufficiency of cold water to take away all its heat, which is greater than weaker steam, though not in direct proportion to its elastic force.

Mr. Watt's first specification (1769) describes the method of working by cooling or reducing the force of the steam, without wholly condensing it; but it has always been found most advantageous to condense effectually, even though the power necessary to draw out the injection-water from the condenser is considerable: the engine, in consequence of the greater perfection of the vacuum, is well able to afford this deduction. The most advantageous application of highly heated steam is on Mr. Watt's principle of admitting it in its full power, for a small portion of the descent of the piston; and then shutting off the supply, the remainder of the action is effected by the expansive force of that portion

of steam already admitted. But to obtain the full advantage of the varying forces, it is necessary to have some contrivance, by which the effect of the engine, on the work which it is performing, shall be uniform, or nearly so. Mr. Watt's specification of 1782 contains a great number of different methods: first, by chains acting upon spirals, on the principle of the fusee; secondly, by levers acting unequally upon each other; thirdly, by a large weight attached to the working-beam, at a considerable height above the centre of motion. When the piston begins its descent, this weight will oppose itself to the motion of the piston, until the descent of the latter has inclined the beam so much, that the centre of gravity of the weight is perpendicularly over the centre of motion of the beam: the weight has then no effect on the engine; but after it has passed this position, it must evidently tend to aid the effort of the piston to draw up the load of water in the pumps. And it is possible so to adjust the weight in its position, quantity, and height above the centre of the beam, that it will very nearly equalize the diminishing force of the piston; but this must be when the steam is always stopped at the same proportion of the total descent.

Fourthly: Another method, which is very ingenious, is to have two large cylinders or pumps, open at top and bottom, and each furnished with a piston without valves. The pistons of the two are suspended from the opposite ends of the beam, so that the descent of one will produce the ascent of the other. The cylinders are filled with water, which is conducted by a large trough from the top of one cylinder to the top of the other, so that the water is alternately transferred from one to the other. Suppose each piston at the middle of its respective cylinder, the water will be equally divided between them upon their pistons, and will hang in equilibrio on the beam; but suppose one end of the beam depressed, the piston suspended from the opposite end will rise and raise up part of the water, which rests upon it, into the trough, by which it will run into the opposite cylinder; and as the corresponding descent of that piston has made room for it, the water becomes unequally divided. When one piston is at the top of its cylinder, the other will be at the bottom, and have the whole of the water resting upon it. Suppose this piston to be that one which is at the outer end of the beam, the steam-piston will be at the top of the cylinder; then if steam be admitted, it will press down the steam-piston, and draw up the water in the cylinder at the outer end of the beam. The weight of this water opposes the motion of the steam-piston, because the whole of the water in the water-cylinder must be lifted; but by the time the steam-piston has descended one-third or one-fourth, and the steam is shut off, the pressure on the steam-piston begins to diminish. The weight of the water on the water-piston has diminished also, because part of the water in it has run off by the trough, and entered into the opposite cylinder, where its weight upon the water-piston tends to aid the steam-piston in descending; and this aid continues to increase as the steam-piston descends farther, by the water being regularly transferred from the ascending to the descending water-piston; until the whole of it rests upon that piston which is at the bottom of its stroke. It is evident that the same action must take place in returning, and therefore this contrivance is only applicable to a double acting engine, and such engines are not commonly used for pumping water.

The application of any of these ingenious contrivances to the vast engines employed in pumping would be attended with great difficulties; and if attempted to be used to equalize the action of the expansive principle, when ap-

plied to its fullest extent, would, we think, be impracticable: we mean, when steam of great elastic pressure is employed, and when the stoppage of the supply is made to take place at a very small portion of the descent. In this case, the strain upon the centres of the snails or levers, sufficiently oblique to equalize the action, would be beyond all bounds. Lord Stanhope has applied the principle of Mr. Watt's levers, in the most judicious manner, to the printing-press. (See PRINTING.) But in so small a machine, worked only by the strength of one man, the strong cast-iron frame of the press has been frequently broken.

We suppose it is for such reasons, that Messrs. Boulton and Watt have not, that we know of, applied these contrivances to any of their engines, but have contented themselves with employing steam a little more than the pressure of the atmosphere, and stopping the supply at one-fourth or one-third of the descent, according to the circumstances under which the engine works. In this case, the decreasing pressure in a large engine is not much greater than to counteract the acceleration, and aided by the momentum of the heavy working beam, pump-rods, and rising column of water, produces nearly uniform motion.

Mr. Hornblower, about 1781, had a patent for a method of applying the expansive principle of Mr. Watt in two successive cylinders in such a manner, as to approach more nearly to an equality of force, by which steam of great pressure can be employed to act by its expansion. This kind of engine, of which a description is to be found in Mr. Watt's specification of 1782, has since been brought to a great degree of perfection by Mr. Woolf, as we shall notice.

Description of Messrs. Watt and Boulton's complete Single Engine. — Plate III. *fig. 1.* is taken from the engine at Chelsea water-works, for pumping water for the supply of London: it was erected in 1804, and is estimated at fifty horses' power. — We have hitherto considered Mr. Watt's engine as being fitted up with the great wooden beam, and arch-heads, chains, and pumps, the same as the old engine. This was the form of the engine for some years; but since 1784, when Mr. Watt invented the parallel motion for his double acting engine for turning mills, that ingenious contrivance has been applied to the pumping engines, instead of the arch-head and chains, as being more correct in its action. Also, for about fifteen years past, they have employed cast-iron working beams instead of wood. *ABC* is the beam, which is made of cast-iron instead of wood, and is composed of two large plates, of the shape represented in the figure, put together at twelve inches distance from each other, leaving a space between them, the centre or axis *B* passing through the middle of both plates. The axis lies on the floor *D*, which is sustained by the wall *E*, built beneath the centre. *Q* is the cylinder, contained within a steam-jacket, composed of segments screwed together. *FF* is the steam-pipe coming from the boiler *G*. *ab* is the piston-rod, connected with the end, *C*, of the beam by links *C, b*; and whilst the upper ends of these links move in the arc of a circle, with the end of the beam, the lower ends, *b*, are made to accommodate themselves to the vertical motion of the piston-rod *a*, by means of the rods, *c*, extending to the smaller links, *d*, which form a parallelogram. The motion of the parallelogram is governed by the bridle-rods, which move about a fixed centre *m*. The action of this contrivance is fully explained under the article *Parallel Motion*; and it is enough for our present purpose to understand, that the lower ends, *b*, of the links, *b, C*, will ascend and descend in a perpendicular right line. A similar motion, but of half the quantity, is given to the rod, *R*, which works the air-pump, *N*, of the engine at the lower

end, and the middle part of the rod has the plug-beam, *R*, attached to it, which has pins, or chocks, screwed on it to actuate the handles, *x, y*, and *z*, of the mechanism for the valves, which mechanism is very different from that employed in the old engines, and even from that of the first engines of Mr. Watt. But to describe all the varieties which have been adopted, would occupy a volume, and afford information of but little value.

The pump-rod, *p*, is suspended at the end, *A*, of the beam by another parallel motion, and the upper part, *S*, of the rod is made of cast-iron, and very massive, to have a sufficient weight in itself to draw up the piston, and make the returning stroke. The real pump-rod, *p*, is jointed to the heavy counter-weight *S*, and is polished, like the piston-rod *a*, that it may slide through a collar of leathers in the head of the pump *Y*, because the pump is of that kind called lifting force-pumps; its bucket raises the water in ascending, but it forces it through the air-vessel *T*, and pipe *X*, which leads to a reservoir two miles distant, in Hyde Park, and elevated 150 feet above the level of the water in the well where the pump draws from. This well has a communication with the river.

The cylinder, *Q*, is kept down by the weight of a pier of masonry, on which it is placed, and large iron bolts, *n*, descend from the lower flanch to the groundfills, upon which the masonry is built. Immediately before the pier is the condensing cistern, *M*, which contains the air-pump *N*, the condenser *L*, partly concealed, and hot-well *g*, and is kept supplied with cold water by the cold-water pump *I*, worked by the beam at the outer end, and the waste runs off again into the well, so as to keep the water in the cistern always cold.

The valves, which must be opened and shut to produce the action of the engine, are four in number; viz. the upper steam-valve at *F*, the lower steam-valve *O*, and the exhaustion-valve *K*, *fig. 2*, and a small valve *l*, beneath the water in the cistern *M*, to admit the injection into the condenser: but these parts are better explained in *fig. 2*, which is a section of the cylinder, air-pump, and condenser on a double scale.

A, the section of the cylinder, in which the piston, *X*, moves; *F*, the steam-pipe coming from the boiler; *L*, the condenser; *N*, the air or discharging-pump; *m*, a passage or pipe from the pump *L*, to the condenser *N*, in which passage is an occasional communication by a haucing-valve at *m*, which shuts towards the condenser; *l* is the injection-valve, to be lifted by the engine at every stroke, for the purpose of condensing the steam in the condenser *L*; *w* is the snifting or blowing-valve, placed outside the condensing cistern (of which *MM* is a section, on purpose to shew the contents); the snifting-valve, *w*, communicates with the condenser by a pipe passing through the side of the cistern *M*, and is inserted at the side of the condenser; *K* is the exhaustion-valve, to be lifted by the engine, and open a communication between the cylinder *A* and the condenser *L*; *O* is the steam-valve, to be lifted by the engine, and open a communication between the lower part of the cylinder, and upper part thereof, through the steam-pipe *r*; and *F* is the upper steam-valve of the same kind, opening a passage from the boiler to the top of the cylinder; and thence by the pipe *r*, and valves *O, K*, to all parts of the engine.

We must now attend to the mechanism by which the engine is made to feed itself, and perform its reciprocations. The valves are lifted by means of a lever applied to each, within the iron box in which it is contained, entering into an opening in the stem of the valve; and a second lever is fixed on the axis of the lever, on the outside of the box, to be connected

with the levers and handles *x*, *y*, *z*, which open and shut the valves. There are three separate axes, or spindles, placed parallel and above one another, and each has a handle or spanner *x*, *y*, *z*, by which it is moved, either by the hand, to start the engine, or by the chocks on the plug-beam *R*, when the engine is in action. The two upper spindles, *x* and *y*, have short levers projecting from them towards the cylinder; and from each of these levers a rod is suspended, with a sufficient weight, *o*, at the lower end to turn round the spindle, each upon its axis, in that direction which will cause the handles, *x* and *y*, to fly upwards. Also the lower spindle has a lever projecting from it, away from the cylinder, with a heavy weight, *n*, fixed at the end; but this being applied, on the opposite side, to the weights of the two upper handles *x*, *y*, the weight, *n*, causes the handle, *z*, to descend. Both the axes of the lower handles, *y*, *z*, have small levers, or catches, 1 and 2, which act in the hooks of a double latch, or detent, *t* *v*, which is moveable upon a centre-pin situated between the two axes. The hooks of this detent are to detain the catches of the spindles, and prevent the handles, *y*, *z*, from moving by the action of their respective weights, until the detent is moved on its centre, so as to relieve the catches of the levers from its hooks *t*, *v*. But it is evident, from *fig. A*, that when only one catch, as 2, is hooked by the lower hook, *v*, of the detent, and consequently the weight of its spindle is held up, if the other catch, 1, is moved by depressing its handle, *y*, so as to raise its weight in the act of entering the hook, *t*, of the detent, it will press the end, *t*, of the detent forwards upon its centre, and this at the same time pressing back the hook, *v*, at the opposite end of the detent, releases the catch, 2, of the lower handle, *z*, therefrom, and the weight, *n*, on that spindle immediately falls.

The spindle of the upper handle, *x*, is devoted to opening and shutting the upper steam-valve *F*, having a lever which communicates by a rod, 2, with the lever, 3, of that valve; so that by pressing down the handle *x*, it will shut the valve *F*. The weight *o*, which is applied to the upper spindle, tends to lift up the handle *x*, and open the valve *F*; and when the upper handle, *x*, is depressed, the valve will be shut; or when the handle is suffered to fly up by the action of its weight, it will open the valve.

The second spindle, *y*, has a lever communicating with the lever of the exhausting-valve *K*, by a rod 4. The weight *o*, applied to this like the former, tends to lift up the handle *y*, and draw open the valve; but when the handle, *y*, is depressed, the valve is shut, and in this position the catch, 1, is held down by the hook, *t*, of the detent before explained, and retains the valve shut.

Lastly, the lower spindle, *z*, is for the lower steam-valve *O*, which is opened by the rod 14, when the handle, *z*, is suffered to fall down, and shut when the same is up, being held by the catch 2, and hook *v*. In all these the weight tends to open the valve; but when the valve is to be kept shut, the detent holds the weight up. Now, by removing the detent, the weight falls and opens the valve in an instant.

The upper spindle has no detent to detain it; but what is equivalent is a rod, 5, jointed to that lever of the middle axis which has its weight and rod, *o*, suspended from it. The upper end of the rod, 5, is made with a loop, or long slit, in which works a pin at the end of a lever, 6, projecting from the upper axis towards the cylinder. The consequence of this is, that while the middle axis is detained by its catch, and detent *t*, to keep the exhausting-valve, *K*, shut; the lever, 6, of the upper spindle will be borne up by its pin resting in the bottom of the loop of the rod, 5,

so as to keep the weight from opening the upper steam-valve *F*, as long as the exhausting-valve is kept shut; but when the catch, 1 *t*, of the middle axis is discharged, and its weight has opened the exhausting-valve, the looped rod, 5, will no longer support the lever, 6, of the upper axis, but allows its weight to descend and open the upper steam-valve; but at the same time the upper steam-valve, *F*, is not confined to be always open when the exhausting-valve, *K*, is open; for the upper steam-valve may be shut by depressing the upper handle *x*, without affecting the exhausting-valve at all, because the slit, or loop, in the top of the rod, 5, allows that motion. This property must be attended to, because the action of the engine, by expansion, depends upon it. We have not before noticed the injection-valve, from which a long wire ascends, and is attached to a strap, 9, which winds upon the middle axis; therefore, when the middle handle, *y*, flies up by its weight, it winds the strap, and opens the injection-valve at the same instant that the exhausting-valve is opened.

The injection-valve, *I*, is placed to close the orifice at the end of a short curved pipe, which enters into the condenser and turns up; and the pipe has a cock in it, between the valve and the condenser, to cut off the communication, or to regulate the supply of injection when the valve is opened. This cock must be always shut when the engine is not at work, to prevent the condenser filling with water.

Operation of the Engine.—We will now consider the action of the engine. Suppose the fire lighted beneath the boiler *G*; all the valves are kept shut by pressing down the two upper handles *x* and *y*, and lifting up the lower one, their respective catches detaining them in those positions, until the steam is sufficiently heated, and the engine is ready to work. In the quiescent position of the engine, when it is at rest, the counter-weight always draws the piston fully at the top of its cylinder, as in the figure; the air-pump bucket will also be at the top of its barrel.

In order to prepare for setting the engine to work, all the three valves must be opened at once. This is done by relieving the spindles from their several catches, when the weights immediately open the valves. The steam enters through the valve *F*, into the top of the cylinder, and by the pipe *r*, through the lower steam-valve, *O*, into the bottom of the cylinder; also through the exhausting-valve *K*, into the condenser *L*, driving before it some air, which passes out at the snifting-valve *w*. At first, the coldness of the parts condenses all the steam which enters; and it is not until all the iron, with which the steam comes in contact, is heated to the temperature of boiling water, that the steam ceases to flow from the boiler in a stream, and be condensed as it arrives at the cylinder and condenser; but after this, the steam acquires the same force in the cylinder and pipes that it has in the boiler: it then occupies every cavity and crevice of the engine, and in a little while displaces all the air in the cylinder, condenser, and pipes, which passes out, and is discharged at the snifting-valve *w*. This valve is always covered with water in a small cistern attached to the side of the large one, to ensure its tightness. Through this valve the air is discharged by the steam, not at every stroke, as in Newcomen's engine, but only at first setting the engine to work, and this operation is called the *blowing through*. It is well known when the cylinder and other vessels are properly heated, and the air discharged, by a very smart crackling noise at that valve, like a violent decrepitation of salt in the fire; this noise being occasioned by the water in the small cistern producing a sudden and rapid condensation of the issuing steam when the air is all gone.

It being known by this sign that all parts of the engine are cleared of air, all the three valves are to be shut, by pressing and holding down the two upper handles *x, y*, and lifting up the lower handle *z*, in which situation its catch, *2*, will retain it. This cuts off the farther supply of steam from the boiler, and also intercepts the passage of the steam from the cylinder to the condenser; and as the cold surface of the condenser still continues to condense a considerable portion of steam, there will soon be none left, and a vacuum will be formed in the condenser, while the cylinder both above and below the piston is full of steam. The vacuum in the condenser will soon become perfect from the external cold alone, though more slowly than when an injection is made.

In this state the engine is prepared for starting at a moment's notice, by the engine-man letting the two upper handles, *x* and *y*, rise up, by their respective weights: this opens the upper steam-valve, and the exhausting and injection-valves; the former admits the steam into the top of the cylinder, to press upon the piston; while the latter allows the steam, already in the lower part of the cylinder, to flow into the vacuum condenser; and at the same instant that he opens the injection-cock, the valve is lifted at the same time with the exhausting-valve: this admits a jet of cold water into the condenser, and condenses the steam as fast as it arrives from the cylinder, so that in an instant all the steam in the lower part of the cylinder will be drawn off and condensed. The pressure of the steam on the piston being now unbalanced by any thing beneath the piston, it descends and draws up the pump-buckets, and columns of water in the pumps, with a velocity proportioned to the pressure of the steam, and the diameter of the piston, compared with the height of the column of water in the pumps, and the diameter of the bucket: but the piston having descended about one-third of its stroke, a chock of the plug-frame, *R*, meets the upper handle *x*, and pressing it down, shuts off the steam from the boiler. That part of the handle on which the chock acts becomes perpendicular when the valve is shut, the handle being bent for that purpose; and the chock can therefore descend farther, and slide again! the perpendicular part of the handle, which is straight, without producing any farther depression of the handle, at the same time that it keeps it down to the same point, so as to hold the valve shut. The piston, therefore, continues its descent by the farther expansion of the quantity of steam at first let into the cylinder; but having arrived at the bottom of its stroke, a chock on the opposite side of the plug-beam, *R*, seizes the middle handle, *y*, and presses it down, which pushes the rod, *4*, until it shuts the exhausting-valve *K*, and also shuts the injection-valve by the strap and rod *g*. When the catch, *1*, of this handle, *y*, presses on the upper hook, *t*, of the detent *10*, it relieves the catch, *2*, of the lower axle *z*, and then the weight, *n*, causes the handle, *z*, to fall, and pulling the rod *14*, opens the lower steam-valve *O*. Let us now consider the position of the engine; the middle handle, *y*, will be held down by its catch, *1*, holding in the upper hook, *t*, of the detent, so as to keep the exhausting-valve, *K*, shut; and the upper steam-valve, *F*, is also kept shut, by the same means which kept it shut during the latter two-thirds of the descent of the piston.

Under these circumstances the piston is at liberty to rise by the action of the counter-weight *S*, because the opening of the lower steam-valve, *O*, has established a free communication between the top and bottom of the cylinder, and the steam in the top of the cylinder can flow through the pipe *x*, and enter the bottom of the cylinder, as fast as the piston rises, by the action of the counter-weight.

When the piston has returned to within one-third of the top of the cylinder, the chock of the plug-frame quits the up-

per handle *x*; but this handle cannot yet be thrown up by its weight to open the upper valve, because the rod, *5*, from the lever of the middle axis bears up the short lever, *6*, of the upper axis *x*; and thus the motion continues, till the piston arrives very nearly at the top of the cylinder: a chock on the plug-frame then seizes the lower handle *z*, and lifting it up, shuts the lower steam-valve; and the catch, *2*, of the lower axis passing the lower hook, *v*, of the detent, moves it on its centre, so as to release the catch, *1*, of the middle axis from the upper hook, *t*, of the detent. This being the case, the weight of the middle axis causes its handle, *y*, to fly up, and by the rod, *4*, it opens the exhausting-valve; and by drawing the strap and rod, *g*, it opens the injection-valve; at the same time the upper axis, *x*, losing the support of the rod *5*, which kept it up, its weight carries up the upper handle *x*, and by pulling the rod, *2*, it opens the upper steam-valve *F*.

The steam from the boiler is now admitted to press upon the upper surface of the piston, while the steam from the lower part of the cylinder beneath the piston rushes into the condenser, where being met by the cold injection, it is condensed, and makes a vacuum in the lower part of the cylinder, which brings down the piston to make another stroke.

At one-third of the descent, the plug-frame, as before, presses and holds down the upper handle *x*, to keep the upper steam-valve shut; and when the piston has arrived at the bottom, the plug-frame presses down the middle handle *y*, to shut the injection and the exhausting-valves; and in catching, this discharges the lower axis, and the weight thereof opens the lower steam-valve. The piston then rises by the counter-weight, and when at the top of its stroke, the plug-frame lifts the lower handle *z*, and shuts the lower steam-valve; and in catching, discharges the two other handles, which open the upper steam-valve, the exhausting-valve, and the injection-valve, and this produces the descent of the piston, as before.

If the air has been fully discharged from all parts of the engine by blowing through, the action of the air-pump does not begin until the injection-water and the air, which are extricated from the water in the boiling, have accumulated in some quantity in the condenser; then at every descent of the bucket, *d*, of the air-pump, it dips into the water contained in the bottom of the barrel *N*, and the water passes through the valves in the bucket: these valves shut when the bucket is drawn up, lifting all that water which is above them up to the top of the barrel, and there it is forced out through the hanging-valve *g*, into the hot-well *g*. The drawing up of the bucket at the same time makes a vacuum in the pump-barrel beneath it; and if this vacuum is more perfect than that in the condenser, which it will be, if the condenser contains either air or steam, it will press by its elasticity upon the surface of the water in the lower part of the condenser, and force it through the hanging-valve at *m*, into the lower part of the barrel, *N*, of the air-pump; and when all the water is gone from the condenser, the air or elastic vapour which is in the condenser will follow and enter into the pump, until the space of the barrel beneath the bucket is filled equally with the condenser.

This takes place while the pump-bucket is at the top of its barrel; and on the descent of the bucket, the space beneath it is diminished, until it compresses this rarefied vapour so much, that its elasticity will be sufficient to close the hanging-valve *m*, and to lift the valves in the bucket *d*, and pass through them into the space of the barrel above the bucket; and when the bucket has descended to the very lowest, the water contained in the bottom of the barrel, not being able to escape through *m*, must pass up through the valves, and rest upon the bucket *d*. When the bucket ascends, it carries

before it this water and air, and as it rises the space of the barrel above the bucket diminishes, and the rare vapour or air in it condenses by being crowded into less space, until at last it becomes equally dense with the atmospheric air, and then the water following it, drives it through the valve, *g*, into the open air.

The ascent of the bucket, *d*, left a vacuum beneath it, as before, and this drew a portion of the air or vapour from the condenser into it, ready to be extracted by the next stroke. As soon as the bucket begins to return, the discharge-valve, *g*, shuts, and prevents the atmospheric air from entering into the pump. By this we see, that if the vapour in the condenser is so rare that the whole contents of the barrel of the pump will only make a few cubic inches, when reduced to become equal to the pressure of the atmosphere, this small quantity will be effectually evacuated through the discharge-valve *g*, because the water resting upon the bucket follows the air, and will chase every particle of it from the top of the pump, and then follow itself.

The air-pump of Mr. Watt's engine requires to be of large dimensions, and the condenser is generally of the same size, by which means the rarefaction of any elastic vapour contained in the condenser will be equal to half at every stroke; that is, the air-pump will extract half the quantity of the elastic vapour every time; because, supposing the vacuum space which the bucket of the pump leaves beneath it, when it is drawn up, to be equal to the capacity of the condenser, then the vapour in the condenser must expand itself to fill a double space, by which one half of it will enter into the pump, and be drawn out by the succeeding stroke, while the other half will remain in the condenser.

The cylinder at Chelsea is four feet diameter, and eight feet stroke, and the air-pump two feet diameter, and four feet stroke: thus, their areas respectively are as one to four, and their capacities as one to eight. But it must not be considered that this large pump, full of air, is to be drawn out of the condenser at every stroke; for, as we have stated before, the vapour with which it is filled reduces itself to a small quantity before it comes to the density of atmospheric air. At first sight we should be led to conclude, that the pump affects the power of the engine, as a deduction, of as much power as the pressure of the air upon the surface of its bucket; but if we consider its construction, having a valve at *g* to keep off the pressure of the atmosphere, it is certain its bucket can have little weight upon the engine, until the bucket is near the highest limits of the stroke; and taking the sum of the resistance, from the commencement of the stroke to its termination, it will be found to be very little in comparison with the power of the cylinder.

An air-pump of one-eighth the capacity of the cylinder is sufficient to keep the condenser empty when it is a single engine. If a smaller air-pump were employed, it must be in action to lift out the air and water, for a greater portion of its stroke.

In fact, whatever the size of the air-pump may be, it will occasion little more resistance to the engine than from the friction of its bucket, except during the time that it has actually opened the valve, *g*, to discharge the air or water which it contains: before that period, the resistance is only that of compressing the vapour, an operation which begins at nothing, but increases by an ascending proportion reverse to that of the decrease of the pressure of the steam, when acting in the cylinder by expansion, as we have before explained.

In Mr. Watt's early engines, the air-pump and condensing cistern were placed at the outer end of the beam; and there are some reasons to prefer that mode of construction, where the building will admit of it. In this case, the pump-bucket

being drawn up by the descent of the piston, the engine requires a less counter-weight than in the form just described, in which the air-pump must be wholly worked by the counter-weight. Also, it is during the descent of the piston that the action of the air-pump is most necessary; and it is possible that an engine, having the pump worked by the outer end of the beam, may make a better vacuum than when it is worked by the inner end, because there may be some, though a very slight impulse given to the remaining air of the last stroke, by the rush of steam into the condenser at the instant the steam-piston begins to descend, and the air-pump to rise; for no sooner is the exhausting-valve opened, than the steam rushes towards the condenser, and giving a momentary tendency to a plenum therein, may give a push to the air through the hanging-valve, between the pump and the condenser; and hence it is reasonable to conclude, that more air will enter the pump by this means, than if it were left to its own expansion.

It is necessary that the parts appropriated to the condensation of steam should be kept as cold as possible, and those intended for the operation, or passage of the steam, as hot as possible; hence the air or discharging pump and condenser are placed in the cistern of cold water, which is kept constantly full by the cold-water pump, and a little running away into the well, to carry off the excess of heat; and if the injection-valve is placed low in this cistern, it will take the water in the coldest state. The injection-valve and cock are seen in *fig. 2*.

As the condensing apparatus is immersed in water, to be kept cold, so the cylinder should, if possible, be immersed in steam, to be kept hot; for which purpose, Mr. Watt from the first used a casing or jacket round the cylinder, and also at the top and bottom: this was attended with very beneficial effects, although it enlarged the steam surface, and exposed the external jacket to a more rapid condensation than would have taken place from the surface of the cylinder itself. But to have the vacuum as perfect as possible, it is necessary that the cylinder be kept up to such a temperature, as to prevent the least condensation of the steam upon the internal surface, either above or below the piston; because, if the sides of the cylinder were to be wet, as in the common atmospheric engine, the vacuum would be vitiated, as there would be occasioned by this wetness a moisture gradually forming to steam, which the outside casing prevents, when filled with steam from the boiler, and the heat which escapes from the surface of the jacket does not injure the operation of the engine; but if it were possible to cover this outward case again with any sort of substance which would entirely prevent the transmission of heat from the casing, it would supersede the use of the jacket altogether, and would apply with more advantage to the cylinder itself; but we do not know of any substance which will not admit this transmission more or less. Some of Messrs. Watt and Boulton's best engines we have seen surrounded by a case of polished copper, we believe outside of the jacket.

In small engines, it is common to place the cylinder within the boiler, and it must then be kept fully as hot as the steam which enters it; but this is not practicable in a large engine, nor is it advisable in any case, because the frequent repairs which the boiler requires must derange all parts of the engine.

When the jacket is used, a small copper pipe is conducted from the steam-pipe to keep it full. As the jacket of a large cylinder must be exposed to be heated or cooled less than the metal cylinder to which it is attached, the unequal expansion might break the joints; to avoid this, the jacket is made in two halves, put together in the middle of

the length, without any other attachment than that of entering into each other for three or four inches, with a cup which is packed with hemp and tallow. The steam-pipe has a similar joint at *b*, *fig. 2*, which unites it to the box of the exhausting-valve *K*, and will admit of drawing out a little.

Description of other Parts of Mr. Watt's Engine.—In the drawing (*fig. 1.*) in our plate, the condenser is represented at one side of the air-pump, in which situation it partly conceals the pump. In *fig. 2.* they are put into a different position for explanation, the condenser being represented beneath the cylinder. The eduction-pipe is carried sideways from the box in which the eduction-valve is situated, so that the condenser can be placed in any situation which is convenient.

13, 13, are the catch-pins, which are firmly fixed to each end of the beam, and limit the motion of the engine by coming down to strike upon the beams of the floor *D*, if the engine makes too long a stroke; and pieces of cork are laid on the floor to soften the blow with which it would otherwise strike. It once happened to this engine, that the valve of the pump-bucket breaking, the engine suddenly lost its load, or resistance, which occasioned the piston to descend, and strike on the spring-beams, or floor *D*, for two or three successive strokes, with such violence as to break one of the beams; and at last the piston striking the bottom of the cylinder, the momentum of the beam forced down upon the rod so violently, as to bend the great piston-rod quite crooked. To prevent similar accidents, a smaller steam-pipe was added at the side of the vertical steam-pipe, communicating with the passage into the bottom of the cylinder: this pipe is kept closed by a valve; but if the engine descends so low as to strike on the spring-beam *D*, the catch-pin, 13, of the beam strikes a small lever 10, and by the communication wire, 11, opens the valve, and lets the steam into the lower part of the cylinder, beneath the piston, and this destroys the vacuum, so as to prevent the farther descent of the piston.

There is also a small spring-catch or detent, which tends to spring under the lever of the upper steam-valve, and prevent it from descending. This catch is held back by a second catch, which is relieved when the catch-pin strikes the lever 10, and then the first-mentioned detent, by retaining the steam-valve from being opened, prevents any danger of the engine making a repetition of the stroke while it has no load.

Boiler.—The boiler of the engine we have not mentioned before; it is set in a furnace, so as to receive the heat of the fire, and the flame passes through a long flue, which goes twice round the bottom part of the boiler, to give as much as possible of its heat to the water before it enters into the chimney. The steam-pipe, *F*, has a throttle-valve in it at 30, which regulates the supply of steam to the cylinder. This valve is not a conical spindle-valve, the same as the other valves of the engine, but is a circular plate of metal, made to fit the bore of the pipe, and is moveable upon an axis, which passes diametrically across the plate; and the end of the axis, where it comes to the outside, has a lever fixed on it to communicate motion to the valve, which being turned edgeways in the pipe, presents scarcely any resistance to the passage of the steam; but when turned flat across the pipe, it stops its bore; and although it is not fitted with any extraordinary care, it is sufficient to regulate the steam. This kind of throttle-valve is preferable, because it can be moved by a very slight force.

Regulator.—There is a contrivance to regulate the velocity of the engine, by a small pipe proceeding from the air-vessel of the pump; it conveys water to the lower part of a

small vertical cylinder, into which a piston is fitted, and loaded with a heavy weight; then if the engine works too fast, so as to force more water into the air-vessel than the main pipes, *X*, will carry off, it must make a greater pressure and condensation of the air in the air-vessel, until the water is forced to run quicker through the main-pipe, and this pressure being also communicated by the small pipe to the regulating cylinder before-mentioned, causes its piston to lift the weight and rise up, and this motion is communicated by a wire to the throttle-valve, so as to close it and diminish the supply of steam; or, on the other hand, if the engine works too slow, the pressure in the air-vessel must diminish, and then the loaded piston will sink and open the throttle-valve a small quantity, to admit more steam.

It should have been mentioned before, that the weight with which the piston of this regulating cylinder is loaded, is so contrived, that it will increase in force as the piston ascends, and diminish as it descends. There are many ways of doing this, but the one adopted, in this case, is to load the piston with a very heavy cast-iron chain, some of the links of which fall upon the ground as it descends, and relieve the piston from their weight; but as it ascends, it lifts other links off the ground, and becomes more loaded, until it finds itself a place where the load will balance the pressure of the water in the air-vessel.

It is evident that, by this contrivance, the motion of the engine will at all times be so regulated, as to supply just the quantity of water desired; but this quantity can be made greater or less, by applying a greater or less weight to the piston, so that it will sink more or less into its cylinder, before it will come to an equilibrium with the pressure in the air-vessel, and will thus open the throttle-valve more or less. But when the adjustment is once made, it will keep the engine working with regularity at that velocity.

In some of the latest engines erected by Messrs. Watt and Boulton, they have, by an ingenious movement, made the motion of this regulating piston communicate with a long screw, attached to the plug-beam, which regulates the chock that shuts the upper steam-valve at any required portion of the descent of the piston. By this means, although the screw is in constant motion with the plug-beam, the screw is turned so as to regulate the chock on the plug, and measure out the quantity of steam which the engine shall have introduced into the cylinder at each stroke, to enable it to fulfil its task.

It is in these properties of the engine, by which it regulates itself, and provides for all its wants, that the great beauties of the invention consist. M. Belidor, 80 years ago, speaking of the old engine, says: "It must be acknowledged, that this is the most wonderful of all machines, and that nothing of the works of man approaches so near to animal life. Heat is the principle of its movement: there is in its tubes a circulation, like that of the blood in the veins of animals; having valves which open and shut in proper periods, it feeds itself, evacuates such portions of its food as are useless, and draws from its own labours all which is necessary to its own subsistence." To pursue the idea, we may now say of the more perfect machine, that it has what approaches the appetite of animals, in taking that kind and quantity of food which its exigencies require, and in rejecting that which is unnecessary. But we must explain these self-regulators more fully.

Apparatus connected with the Boiler.—In order to know the exact height of the water in the boiler, two gauge-cocks are employed, one of which reaches to within a little of the height or level at which the water should stand, and another reaches a little below that level. If the water stands at the

desired height, the first-mentioned cock, being opened, will give out steam; and the other cock will emit water, in consequence of the pressure of the superincumbent steam on the surface of the water. But if water should issue from both cocks, it will be too high in the boiler; and if steam issues from both, it will be too low. This is the same contrivance which was used in Newcomen's engine; but Mr. Watt applied in his first engines a small vertical glass tube, which has a communication with the boiler by a copper pipe cemented to each end: one pipe, from the top of the glass tube, enters the boiler above the intended level of the water; and the other pipe, from the bottom of the glass tube, enters the boiler below the surface of the water. In this way, it is evident that the glass tube will always be filled with water to the same level as the water in the boiler, and may be graduated with inches, to inform the engine-man when the boiler requires a supply.

Another contrivance is a pipe descending beneath the surface of the water in the boiler, when at its intended level; and in the upper end of the pipe at the top of the house a whistle or mouth-piece is formed: then, if the water in the boiler sinks too low, the steam will issue at the pipe, and, passing through the whistle, will make such a noise as to call the engine-man to his duty, even if he should have fallen asleep. This contrivance is rendered unnecessary by a subsequent one, by which the boiler will always feed itself, exactly as fast as its evaporation of steam requires.

The boiler is kept constantly supplied with water, to repair the waste of evaporation, by means of a small pump 20, which draws hot water from the hot-well *g*, and raises it to such a height, that the water will run through a pipe, shewn by the dotted lines, into the cistern 14, placed over the top of the boiler, at an elevation of some feet. From this cistern a tube, 18, descends into the boiler, and terminates beneath the surface of the water therein, so as to feed the boiler with water. But as it is necessary that the water in the boiler should always be preserved at the same level, this feed-pipe is closed by a valve in the bottom of the cistern 14, which prevents the water running down into the boiler, until the level of the water subsides, and shews that it requires replenishing. A crooked arm, which is attached to the side of the small cistern 14, supports the short lever 15, 16, which moves upon a centre-pin. The extremity, 16, of this lever suspends, by means of the wire 16, a stone or piece of metal, which hangs just below the surface of the water in the boiler. The wire passes through a small stuffing-box in the top of the boiler, to prevent leakage. The other extremity, 15, of the lever is connected by a wire with a valve at the bottom of the cistern 14, which covers the top of the pipe 18; and this end of the lever is loaded with a sufficient weight to balance the stone in the boiler. Now it is a maxim in hydrostatics, that when a heavy body is suspended in a fluid, it loses as much of its weight as equals that of the quantity of fluid which it displaces. When the water in the boiler, therefore, is diminished, by the conversion of part of it into steam, the upper surface of the stone will be above the fluid, and its weight will consequently be increased in proportion to the quantity of its mass that is not immersed. By this addition to its weight, the stone will overcome the balance-weight on the end, 15, of the lever, causing the extremity, 16, of the lever to descend; and in consequence, by elevating the opposite arm 15, will open the valve at the top of the pipe 18, and thus gradually introduce a quantity of water into the boiler equal to that which is carried off by evaporation. This process is continually going on, while the water is converting into steam; and it is evident that too much water

can never be introduced, for as soon as the surface of the water coincides with the surface of the stone, it recovers its former weight, and the valve at the bottom of the cistern, 14, shuts the top of the pipe 18, and prevents any more water entering the boiler, until the float or body, 21, descends by the diminution of the water therein.

When the engine is steadily at work, the stone subsides until it opens the valve to admit a regular stream of water, which will just equal the waste by evaporation; and then the operation will go on regularly, without any action of the float, until something is altered.

We have before stated, that the steam in the boiler is no stronger than the atmosphere; but there would still be great danger of the boiler's bursting, if the steam should accidentally become too strong: the boiler is, therefore, furnished with a safety-valve, which is so loaded, that its weight, added to that of the atmosphere, may exceed the pressure of the interior steam, when of a sufficient strength. As soon as the expansive force so far increases as to become dangerous to the boiler, its pressure preponderates over the pressure of the atmosphere, and the safety-valve is opened, when the steam escapes from the boiler, till its strength is sufficiently diminished; and the safety-valve shuts again, by the predominance of its pressure over that of the interior steam. By opening the safety-valve, the engine may be stopped at pleasure: and to effect this, a small rectangular lever, with equal arms, is fixed upon the side of the valve, and connected with its top. To one of these arms a chain is attached, which is conducted into the engine-house, and passes over a pulley from a horizontal to a vertical direction, so that it hangs like a bell-pull. By pulling it, the valve is opened, and the machine is stopped.

There is also another valve of safety, for the reverse of the object of the first-mentioned safety-valve: it opens internally, and is balanced by a small lever, and a sufficient weight to keep it shut, until the pressure of the steam within the boiler becomes much less than the external air, which then forces open the valve, and enters into the boiler, till the equilibrium is restored. It is evident that this valve can never be necessary so long as the engine is at work; but its use is to prevent the sides of the boiler being crushed in by the weight of the air, when it has done work, and the steam within it cools and condenses.

Self-acting Damper.—By another ingenious contrivance, the boiler is made to regulate the heat of its furnace, in proportion to the quantity of steam which the cylinder draws off from it. For this purpose, a damper or iron sliding-door is fitted into the flue, just where it enters the chimney; and a chain is conducted from it, over pulleys, to any convenient situation, where the engine-man can pull it like a bell-pull, to draw up or lower down the damper, and by that means regulate the draught of air through the furnace, and the heat of the boiler.

To make the damper self-regulating, a large pipe of six or eight inches bore is fixed vertically through the top of the boiler: it is open at top and bottom, but the lower end descends nearly to the bottom of the boiler, so as to be always immersed beneath the surface of the water. Now the steam pressing on the surface of the water in the boiler, and the atmosphere pressing on the surface of the water in the open pipe, it is evident that the relative levels of the water in both will be at all times in exact proportion to the relative elasticity of the air and the steam: and if at any time the pressure of steam diminishes, by the heat of the furnace growing less, or by the engine drawing off more steam, the surface of the water in the open pipe will subside; and as there is a stone-float in this pipe, balanced in the same man-

ner as the feeding-float before described, the descent of the stone is made to operate upon the chain of the damper, and draw it up so as to increase the draught of the furnace, until, by the accession of heat, the steam recovers the intended pressure, and restores the damper to its place. On the other hand, when the pressure of the steam is on the increase, either from the engine being retarded or stopped, or from the furnace burning too fast, the pressure of the steam on the surface of the water in the boiler raises the water in the open pipe; and the stone-float, then rising by its balance-weight, closes the damper, and diminishes the draught, till the steam subsides to its desired force. By this means, the steam is always preserved to the same intensity; a circumstance very necessary to the regularity of the motion of the engine.

Steam-Gauge.—To ascertain the pressure of steam with a greater degree of exactitude than by the load on the surface of the safety-valve, which is liable to many uncertainties, Mr. Watt employs a steam-gauge, consisting of an inverted siphon, or bent tube, of glass or iron; one leg of which is jointed to the steam-pipe, and the other is open to the atmosphere. A quantity of mercury being poured into the tube, it will occupy the bent part which joins the two legs; and the surface of the mercury in one leg being exposed to the pressure of the steam, while the external air acts upon the other, it is evident that the difference of level of the two surfaces will express the pressure of the steam in the height of a column of mercury.

When the tube is of glass, this difference of level may be seen and measured on a scale; but when an iron tube is used, a small light wooden rod is made to float on the surface of the mercury in the open leg, and point out the height on a scale of inches, fixed above the tube. But in this case the divisions, which are numbered for inches, must be only half inches; because, as the mercury descends in one leg as much as it rises in the other, the scale reads double, to shew the difference of level.

Barometer-Gauge.—Mr. Watt has also adapted a gauge, called a barometer, to indicate the degree of vacuum in his engines, an addition which is of important consequence to the good performance of the engine, to the profit of the proprietors, and the credit of the engineer; yet in many engines in London, we see this important instrument either out of repair, or wholly laid aside.

The form of this barometer can be understood without a figure: it is a tube of glass 30 inches long, filled with mercury, and applied to a scale of inches, the lower end being immersed in a cup, in the same manner as the common barometer, or weather-glass; it is, in fact, the same thing as a barometer in every respect, except that the vacuum is not made in the top of the tube, in the Torricellian manner, but by the engine. For this purpose, a small copper tube is conducted from the condenser, and cemented to the top of the glass tube, by which means the surface of the mercury in the tube is relieved from the pressure of the atmosphere; and the weight of the atmosphere, which presses upon the surface of the mercury in the basin, will cause it to mount up in the tube to a greater or less height, according as the vacuum is more or less perfect, or as the atmosphere is more or less heavy; which will be shewn by a common barometer placed at the side of the engine barometer.

The pipe which leads from the condenser to the top of the barometer tube must be provided with a cock, which should be shut when the engine is blowing through, to prevent the steam entering the tube, and blowing the mercury out of it: but the basin for the mercury must be made large enough to contain all the mercury, because, when the engine is not

at work, the air will leak in, and allow the mercury to descend into the basin.

It has been proposed to make the barometer in the form of an inverted siphon, just the same as the common steam-gauge, one leg being made to communicate with the condenser, and the other left open to the air. In this way, the rise of the mercury in one leg produces a corresponding fall of the mercury in the other; but on this account, if the scale is applied to one leg, the divisions must be only half inches, that is, provided the two legs are of the same bore; but if they are of different bores, the scale must not be half, but of a proper proportion, to shew always the difference between the level of the surface of the mercury in the two legs.

These tubes may be made of glass; but if the quicksilver is not very pure, the alloy with which the venders of this article adulterate it is by constant action brought to the surface, and, together with the vapour, make the tube so foul, that no precision can be obtained. Iron is the best material for both parts of the tube, which should be correctly of one diameter, or else the result will be erroneous, as we have before remarked; for it is difficult to graduate a scale by experiment in an iron tube, where the difference of level of the mercury in the legs cannot be seen. This tube must communicate with the condenser by a small copper pipe, and a stop-cock be placed between the gauge and condenser. The index in this instrument is the same as in the steam-gauge, viz. a light deal rod, which is put into the shorter tube; and quicksilver being poured into it within three inches of the end, the rod is put into the tube, and floats on the quicksilver. It is almost needless to remark, that the graduation on this instrument must be inverted with regard to those of a single tube.

The barometer shews the perfection of the vacuum, or the pressure of the atmosphere to enter into the condenser, whilst the steam-gauge shews the pressure of the steam to escape into the air. By adding the height of these two columns together, we have the pressure of the steam upon the piston, provided the throttle-valve is fully open, so that there is no obstruction to the entrance of the steam from the boiler into the cylinder. It would be interesting to have a single gauge made to express this in one; nothing would be more easy than to have a long glass tube bent to an inverted siphon, and one of the legs being connected with the steam-pipe, and the other with the condenser, the difference of level between the two surfaces would at all times express the pressure on the piston.

Counter.—In many of Mr. Watt's engines, a little apparatus is attached to the beam, to ascertain the number of strokes the engine makes in any given time: this contrivance is called the counter, and is a train of wheel-work, working like clock-work, commonly attached to the beam in such a manner, that every stroke made by the engine moves one tooth, so that the index tells how many strokes have been made since last examined. This is so shut up in a box, that no person can gain access to it but the one entrusted with the key. When the box is attached to the beam, the inclination of the beam causes the pendulum to vibrate every time the engine makes a stroke, and thus moves the counter round one tooth for every stroke. In other cases, the box containing the counter is fixed to the spring-beam floor, and at every stroke the beam strikes a small detent, and moves the counter one tooth. It was by the account of this instrument that Messrs. Boulton and Watt charged their portion of the savings for working their engines during the term of Mr. Watt's patent.

Construction of the Valves.—The steam and eduction valves are of that kind called button or conical spindle-

valves. Mr. Watt, in his first essays, employed cocks, and also sliding-valves, such as the regulator or steam-valve of the old engine. But he found them always lose their tightness, after a short time. This is not surprising, when we consider that they are always perfectly dry, and almost burning hot. He was therefore obliged to change them all for spindle-valves, which being truly ground, and nicely fitted in their motions at first, are not found to get out of order by any length of time. Other engineers now use them commonly in the old form of the steam-engine, where, however, there is less necessity for them.

The manner of constructing these valves is as follows.

Fig. 3. represents a valve, with its seat and box; suppose it one of the steam-valves; the box is at the end of the pipe which introduces the steam, and *bb* is the upper part of the pipe, which communicates with the lower part of the cylinder, or with the condenser. At *ee* may be observed a part more faintly shaded than the surrounding parts. This is the seat of the valve, and is a brass or bell-metal ring, turned conical on the outside, so as to fit exactly into a conical part, bored out in cast iron, of the pipe *bb*. This ring or seat is fitted in by cement; and the cone being of a long taper, the ring sticks firmly in it, especially after having been there for some time, and united by rust. The valve itself is a strong brass plate, *D*, turned conical on the edge, so as to fit the conical or inner edge of the seat. These two cones are very nicely ground into each other with emery. This conical joining is much more obtuse than the outer side of the ring *e*; so that although the joint is air-tight, the two pieces do not stick closely together. The valve has a spindle or round tail, *Dc*, which is freely moveable up and down in the hole of a cross-piece extended beneath the ring or seat *ee*; and on the upper side of the valve is a strong piece of metal, *DG*, firmly jointed to it, one side of which is formed into a toothed rack.

A is the section of an iron axle, which turns in holes in the opposite sides of the valve-box; and one of these, where it passes quite through the side of the box, is nicely fitted by grinding, so as to be air-tight; and a stuffing of hemp, well soaked in melted tallow and rosin, is made to furround the outside of the hole, to prevent all ingress of air. The end of this axle projects a good way without the box, and carries a spanner or handle *3*, which is connected by a rod with a lever, moved by the plug-frame. To the axis, *A*, is fixed a strong piece of metal, or sector, the edge of which is formed into an arc of a circle, having the axis, *A*, in its centre, and is cut into teeth, which work in the teeth of the rack *DG*, on the valve, and lift the same when the sector is moved. *KK* is a cover, which is fixed by screws to the top of the box *F*, and may be taken off, in order to get at the valve when it needs repairs. From this description it is easy to see, that by turning the handle *3*, which is on the axis *A*, the sector must lift up the valve by means of its toothed rack *DG*, till the upper end of the rack touches the top or cover *K*; and turning the handle, *3*, in the opposite direction, brings the valve down again to its seat.

The force requisite to lift up a large valve from its seat is very great, the valve being kept down by a pressure of the steam upon its upper surface while there is a vacuum beneath it. The valves of the Chelsea engine are nine inches diameter, and therefore contain $(9 \times 9 = 81 \times .7854 =) 63\frac{1}{2}$ square inches, and each being pressed by at least 13 lbs., makes 826 lbs. weight to keep the valve down; and this should, if possible, be lifted in an instant, to admit the steam to pass off without delay. One method of balancing this weight is by means of a small piston, applied beneath the valve. Thus, the lower part of the pipe or box in which the valve is contained, is bored out to a short cylinder, and a

piston is truly fitted therein, as shewn beneath *K*, *fig. 2*: a cover or bottom is screwed on to close the lower end of the short cylinder; and there is a small copper pipe from the jacket, which admits steam into the space of the short cylinder beneath its piston, while there is a vacuum in the box in which the valve is contained, and which is open to the upper surface of the piston. The axis of the valve being connected with the piston, it is evident that the action of the piston to ascend will counteract that of the valve to descend; and, therefore, by apportioning the area of the piston to that of the valve, it may be made to lift with the slightest force.

Even without this contrivance, which is only applied beneath the exhausting-valve, as is seen in the section, *fig. 2*, Mr. Watt invented a very simple and effective method of raising up the valves by levers. The force which holds down the valve is quite momentary; and the instant the valve is detached from its seat the pressure is over, although it has not risen more than a tenth of an inch; the force is, therefore, no impediment to the engine, but would be an inconvenient labour to the man who starts and stops it.

By Mr. Watt's contrivance, the lever is put in such a position when it begins to raise the valve, that its mechanical energy is almost infinitely great. Let *fig. 3.* represent the valve shut, which is supposed to have been just closed by the chock on the plug-beam in its descent coming in contact with the handle *x*, and depressing it, which is moveable with the axis *X*: on this same axis is another arm, *X 2*, connected by a joint with the leading rod *2 3*, which is connected also by a joint with the lever *3 A*, fixed on the axis, *A*, of the sector, contained within the valve-box. Therefore, when the chock of the plug-frame depresses the handle *x*, and turns the arm, *X 2*, round upon its centre, it pushes up the lever, *3 A*, by means of the connecting rod, until the valve is closed, as shewn in *fig. 3*. At that time, the rod *2 3*, and the arm, *X 2*, of the lever, are in one straight line, while the lever *3 A*, (on the axis of the sector,) is at right angles to rod *2 3*, which moves it; consequently the rod is acting with its greatest power to turn the axis *A*, upon which the sector is fixed. In this situation the valve is kept closed by the catch or detent before explained, which holds down the handle *x*, until it is wanted to be opened; the plug-frame then, by lifting the lower handle, relieves the catch, and the weight, *w*, applied to the axis turns it round into the position of the dotted lines, and the lever, *X 2*, draws the rod *2 3*, and, by depressing the lever *3 A*, opens the valve.

From this arrangement, the intelligent mechanic will perceive that, in this position, the force exerted by lever *X 2* is extremely great to pull down the rod *2 3*; and, at the same time, another great advantage arises from this disposition of the levers, which is, that any pressure, however strong, applied upon the valve to open it, would be ineffectual, as that force would be exerted to turn the lever *X 2* endways, in the direction of the axis *X*, instead of turning it round, as shewn by the figure, which represents the valve shut, and retained in that position by the lever.

Construction of the Piston.—In Mr. Watt's first attempt, the greatest difficulty which he encountered was to make the great piston tight. The old and effectual method, by water lying on it, was inadmissible. He was therefore obliged to have his cylinders most nicely bored, perfectly cylindrical, and finely polished; and he made numberless trials of different soft substances for packing his piston, which should be tight without enormous friction, and long remain so, in a situation perfectly dry, and hot almost to burning.

After many trials, he settled the form of the packing which is now universally employed. The piston has a projecting rim

at bottom, which is fitted as accurately to the cylinder as it can be, to leave it at full liberty to rise and fall through the whole length. The part of the piston immediately above this is about two inches less all round than the cylinder, to leave a circular groove or channel, into which the hemp, or soft rope which is called gasket, is rammed, to form the packing; then, to keep the packing in its place, a lid or cover is put over the top of the piston, with a ring or projecting part, which enters into the circular groove for the packing, and pressing upon it, the plate is forced down by screws. The lower part of the groove round the piston being made rounding, with a curve, this pressure on the packing forces it against the inside surface of the cylinder. The piston must be kept supplied with melted grease; for which purpose a funnel is fixed on the top of the cylinder, with a cock and pipe to let the grease down. The stuffing-box in the top of the cylinder, round the piston-rod, is packed with hemp in a similar manner, a collar, with a hole through it for the passage of the rod, being screwed down, to confine the packing in its place.

After all that has been done in this respect, it is probable that the greatest part of the waste of steam which we still perceive in engines, arises from the unavoidable escape by the sides of the piston during its descent. If the piston is packed so tight as totally to prevent the loss, the friction is so increased as to fully outweigh the saving. But it is a fortunate circumstance, that the performance of Mr. Watt's engine is not immediately destroyed, nor, indeed, sensibly diminished, by a small want of tightness in the piston. In the atmospheric engine, if air enters in this way, it immediately puts at stop to the work; but in the new engine, although even a considerable quantity of steam escape past the piston during its descent, the rapidity of condensation is such, that the diminution of pressure is not considerable, and the waste of steam is the greatest inconvenience.

A great many schemes have been since tried to make better methods of packing a piston, but none of them have been brought into use, except the metallic expanding piston, which was proposed by Mr. Cartwright, as we shall notice in describing his engine. Something of the same kind, but not for steam-engines, is to be found in Leupold's *Theatrum Machinarum Hydraulicarum*, 1724.

The actual Performance of Mr. Watt's Engine with respect to Coals.—At the first establishment of their engines, Messrs. Boulton and Watt charged their profits in proportion to the saving of fuel which their engine made, when compared with a common engine burning the same kind of coals. They had one-third of these savings paid them annually, or the payment was redeemed at ten years' purchase. It should be observed, that Mr. Smeaton's improvements were introduced about the same time as Mr. Watt's, and therefore the comparison was not with his engines, but with the former ones. It was Mr. Smeaton's rule, judging from some experiments made before him on some of Mr. Watt's early engines, to estimate Mr. Watt's engine at one-half the consumption of fuel as his own for the same work, in large engines, or a still greater proportion in small engines, because the waste of steam is greater, and he reckoned his own at only one-half of the common engines, as he found them; therefore, Mr. Watt's will be four times as great in effect as the common engines.

As early as 1778, when Mr. Watt first established his engine, we find his proposals, deduced from experiment, were to raise 500,000 cubic feet of water one foot high with one cwt. of coals. He afterwards adopted the denomination of the number of pounds of water which could be lifted one foot high by a bushel of coals as the scale for engines; if we reduce this to the latter term, it will be 24½ millions. Thus, 500,000 cubic feet \times 62.5 lbs.

the weight of a cubic foot of water, = 31,250,000 lbs. of water raised by 112 lbs. of coals. Then say, as 112 lbs. : 31,250,000 lbs. :: 88 lbs. the weight of a bushel of coals, to 24,553,571, the number of pounds of water which will be lifted one foot high with one bushel of coals. Mr. Watt was at that time in expectation of making a great improvement by adopting his expansive method.

Mr. Smeaton, who was desirous of promoting Mr. Watt's discovery, made an experiment in 1778, on an engine on the Birmingham canal, for returning into the reservoir the water let down by the passage of boats through the locks.

The working cylinder was 20 inches, and the pump also 20 inches, lifting 27 feet, at the rate of 11 strokes per minute, of 5 feet 9 inches length each. It worked for an hour with 65 lbs. of Wednesbury coals.

When reduced, this experiment gives about 19 millions lifted one foot by a bushel of coals. Thus, the area of the pump is $(20 \times 20 = 400 \times .7854 =)$ 314 square inches, \times .434 lbs. = 136.27 lbs. weight for every foot in height, \times 27 feet = 3679 lbs. the total weight of the column. The motion per minute is $63\frac{1}{2}$ feet (11 strokes of 5 ft. 9 in. each), or 3795 ft. per hour, \times 3679 lbs. = 13,961,805 lbs. raised 1 foot high per hour. The coals consumed in the hour was 65 lbs.; therefore say, as 65 lbs. : 13,961,805 lbs. :: 88 lbs. : 18,902,136 lbs. raised one foot high with each bushel of coals of 88 lbs.; load on the piston 27 ft. of water, or $(27 \div .434 =)$ 11.7 lbs. per square inch.

When the engines were made to work with the expansion, they were enabled to raise as much as 30,000,000 lbs., but this is when the engines are of the best construction, and working under every advantage of the parts being tight and in the best order; for these circumstances, when neglected, as they usually are by the engine-keepers, make a most material difference in the result.

In the great scale of practical operations this nicety of management cannot be expected; and accordingly, from reports on the engines now working on the mines in Cornwall, which, with the exception of a few of Woolf's engines, are all on Mr. Watt's principle, and most of them constructed by Messrs. Boulton and Watt, taking the average of nine engines, bad, good, and indifferent together, they were found in August, 1811, to raise only 13,500,000 lbs. one foot high for each bushel of coals which they consumed.

But when it was known by the engine-keepers that their engines were under examination, they took so much pains to improve the effects, that by gradual increase, the engines, in 1815, lifted 21,500,000 lbs. taking the average of 33 engines. This information we obtain from the monthly reports of the engines which are working for draining the mines: these were begun in the year 1811, by the agreement of a number of respectable proprietors of the valuable tin and copper mines in Cornwall, who resolved to have ascertained the real work which their respective steam-engines were performing, as it was suspected some of them were not doing duty adequate to the consumption of fuel; and for the greater certainty of attaining their object, it was agreed that a counter should be attached to each engine, and all the engines be put under the superintendence of some respectable and competent engineer, who should report monthly the following particulars in columns: viz. the name of the mine; the size of the working cylinder; whether working single or double; the load per square inch upon the piston; length of the stroke in the cylinder; the number of pump-lifts; the depth in fathoms of each lift; diameter of pumps in inches; time during which they worked; consumption of coals in bushels during that time; number of strokes during the time; length of stroke in the pump; load upon the whole area of the piston in pounds; pounds

lifted one foot high by a bushel of coals; number of strokes *per* minute; and lastly, a column for names of engineers and remarks.

Messrs. Thomas and John Lean were appointed to the general superintendence, and since that time they have published monthly reports: from these we find the following are the three best engines working in 1816.

1st. Stray Park; a 63-inch cylinder, 7 ft. 9 in. stroke, single acting; being one of the three engines on the vast Dolcoath mine. The pressure on each square inch of the piston was 9 lbs. Its performance in four different months was 31, 31½, 28, and 28½ million pounds of water lifted one foot by each bushel of coals.

2dly. Wheal Abraham mine; a single engine, 63-inch cylinder, working an 8 ft. 3 in. stroke, under a pressure of 9.4 lbs. *per* square inch on the piston. Its produce was 22, 29½, and 32 million pounds of water raised a foot high with each bushel of coals. Another month, when the same engine was working with 7.9 lbs. on each square inch of the piston, its produce was 28,318,860 lbs.

3dly. Oatfield new engine; a 70-inch single cylinder, 8 ft. 6 in. stroke, 9.9 lbs. pressure. The effect in different months was 22½, 26½, 29, and 29 million pounds of water raised one foot high by each bushel of coals.

The editor of the *Philosophical Magazine* has drawn out from these reports the average performance of all the engines, as we have mentioned, and the whole of them, for every month up to the end of 1815, will be found in the 46th and 47th vols. of that useful work; as also reports upon Woolf's engine, of which we shall speak in another place. The original reports of Messrs. T. and J. Lean contain information highly interesting to the practical engineer.

In calculating the dimensions of an engine on Mr. Watt's principle to perform any given task, the engineer has less difficulty than in Newcomen's engine, because the pressure on the piston can be so much varied. It is advisable, in general, to take 10 lbs. pressure *per* square inch on the piston for the load; and then, in working the engine, if it becomes necessary, it can be diminished to 9 lbs. or even 7 lbs. or increased to 15 lbs. which is a great latitude for future contingencies.

We have before given the great waste of steam by condensation, on entering into the cold cylinder of the atmospheric engine, which is nearly as great as that which ultimately produces its action; it therefore takes double the supply of fuel which is requisite, if the waste could be avoided.

In the improved engine of Mr. Watt, about 1½ of the quantity of the steam which is necessary to fill the cylinder must be furnished at each stroke; and it is probable that a considerable portion of this waste is from the leakage of the piston, as well as from condensation.

Mr. Hornblower's Double Cylinder Steam-Engine. — The intention of this improvement was to obtain a greater power by a complicated force of the steam, than was supposed could be done by its action in the simple way.

We are not to consider this engine as being on a different principle from Mr. Watt's, but as applying his principles of condensation and expansion in a different manner from what Mr. Watt does. Mr. Hornblower obtained a patent in 1781, for a machine or engine for raising water by means of fire, and the specification of the patent was as follows:

"First: I use two vessels, in which the steam is to act, and which in other engines are called cylinders. Secondly:

I employ the steam after it has acted in the first vessel to operate a second time in the other, by permitting it to expand itself, which I do by connecting the vessels together, and forming proper channels and apertures, whereby the steam shall occasionally go in and out of the said vessels. Thirdly: I condense the steam, by causing it to pass in contact with metalline surfaces, while water is applied to the opposite side. Fourthly: To discharge the engine of the water used to condense the steam, I suspend a column of water in a tube or vessel constructed for that purpose, on the principles of the barometer, the upper end having open communication with the steam-vessels, and the lower end being immersed in a vessel of water. Fifthly: To discharge the air which enters the steam-vessels with the condensing water or otherwise, I introduce it into a separate vessel, whence it is protruded by the admission of steam. Sixthly: That the condensed vapour shall not remain in the steam-vessel in which the steam is condensed, I collect it into another vessel, which has open communication with the steam-vessels, and the water in the mine, reservoir, or river.

"Lastly, in cases where the atmosphere is to be employed to act on the piston, I use a piston so constructed as to admit steam round its periphery, and in contact with the sides of the steam-vessel, thereby to prevent the external air from passing in between the piston and the sides of the steam-vessel."

The following is a description of this engine by the inventor, as it was published in the *Encyclopædia Britannica*. Let A and B (*Plate V. fig. 1.*) represent two cylinders, of which A is the largest; a piston moves in each, having their rods, C and D, moving through collars at E and F. These cylinders may be supplied with steam from the boiler by means of the square pipe G, which has a flanch to connect it with the rest of the steam-pipe. This square part is represented as branching off to both cylinders: *c* and *d* are two cocks, which have handles and tumblers as usual, worked by the plug-beam W. On the fore-side of the cylinders (that is the side next the eye) is represented another communicating pipe, whose section is also square, or rectangular, having also two cocks *a*, *b*. The pipe Y, immediately under the cock *b*, establishes a communication between the upper and lower parts of the small cylinder B, by opening the cock *b*. There is a similar pipe on the other side of the cylinder A, immediately under the cock *d*.

When the cocks *c* and *a* are open, and the cocks *b* and *d* are shut, the steam from the boiler has free admission into the upper part of the small cylinder B, and the steam from the lower part of B has free admission into the upper part of the great cylinder A; but the upper part of each cylinder has no communication with its lower part.

From the bottom of the great cylinder proceeds the education-pipe K, having a valve at its opening into the cylinder; it then bends downward, and is connected with the conical condenser L. The condenser is fixed on a hollow box M, on which stand the pumps N and O, for extracting the air and water, which last runs along the trough T, into a cistern U, from which it is raised by the pump V, for recirculating the boiler, being already nearly boiling hot. Immediately under the condenser there is a spigot-valve, at S, over which is a small jet-pipe, reaching to the bend of the education-pipe K. The whole of the condensing apparatus is contained in a cistern, R, of cold water; a small pipe, P, comes from the side of the condenser, and terminates on the bottom of the trough T, and is there covered with a valve, Q, which is kept tight by the water that is always running over it.

Lastly, the pump-rods, *X*, cause the outer end of the beam to preponderate, so that the quiescent position of the beam is that represented in the figure, the pistons being at the top of the cylinders.

Suppose all the cocks open, and steam coming in copiously from the boiler, and no condensation going on in *L*, the steam must drive out all the air, and at last follow it through the valve *Q*. Now shut the cocks *b* and *d*, and open the valve, *S*, of the condenser; the condensation will immediately commence, and draw off the steam from the lower part of the great cylinder. There is now no pressure on the under side of the piston of the great cylinder *A*, and it immediately descends. The communication, *Y*, between the lower part of the small cylinder *B*, and the upper part of the great cylinder *A*, being open, the steam will go from the lower part of *B*, into the space left by the descent of the piston of *A*. It must, therefore, expand, and its elasticity must diminish, and will no longer balance the pressure of the steam coming from the boiler, and pressing above the piston of *B*.

This piston, therefore, if not withheld by the beam, would descend till it came in equilibrio, from having steam of equal density above and below it. But it cannot descend so fast; for the cylinder *A* is larger than *B*, and the arch of the beam, at which the great piston is suspended, is no longer than the arm which supports the piston of *B*; therefore, when the piston of *B* has descended as far as the beam will permit it, the steam between the two pistons occupies a larger space than it did when both pistons were at the top of their cylinders, and its density diminishes as its bulk increases. The steam beneath the small piston is, therefore, not a balance for the steam on the upper side of the same, and the piston *B* will act to depress the beam with all the difference of these pressures.

The slightest view of the subject must shew the reader, that as the pistons descend, the steam that is between them will grow continually rarer and less elastic, and that both pistons will draw the beam downwards. Suppose now, that each one had reached the bottom of its cylinder, shut the cock *a*, and the education-valve at the bottom of *A*, and open the cocks *b* and *d*. The communication being now established between the upper and lower part of each cylinder, their pistons will be pressed equally on the upper and lower surfaces; in this situation nothing, therefore, hinders the counter-weight from raising the pistons to the top.

Suppose them arrived at the top: the cylinder *B* is at this time filled with steam of the ordinary density; and the cylinder *A* with an equal absolute quantity of steam, but expanded into a larger space. Shut the cocks *b* and *d*, and open the cock *a*, and the education-valve at the bottom of *A*; the condensation will again operate, and cause the pistons to descend; and thus the operation may be repeated as long as steam is supplied; and once full of the cylinder *B*, of ordinary steam, is expended during each working stroke.

The cocks of this engine are composed of two flat circular plates, ground very true to each other, and one of them turns round on a pin through their centres: each is pierced with three sectorial apertures, exactly corresponding with each other, and occupying a little less than one-half of their surfaces. By turning the moveable plate so that the apertures coincide, a large passage is opened for the steam; and by turning it so that the solid part of the one covers the aperture of the other, the cock is shut. Such regulators are now very common in the cast-iron stoves for warming rooms.

Mr. Hornblower's contrivance for making the collars for the piston-rods air-tight, is thus; the collar is in fact two, placed at a small distance from each other; and a small pipe, branching off from the steam-pipe, communicates with the space between the collars. This steam being a little stronger than the pressure of the atmosphere, effectually prevents the air from penetrating through the upper collar; and though a little steam should get through the lower collar into the cylinder *A*, it can do no harm. The manner of making this stuffing-box is as follows: on the top of the cylinder is a box to contain something soft, yet pretty close, to embrace the piston-rod in its motion up and down; and this is usually a sort of plaited rope of white yarn, nicely laid in, and rammed down gently, occupying about a third of its depth; upon that is placed a sort of tripod, having a flat ring of brass for its upper, and another for its lower part; and these rings are in breadth equal to the space between the piston-rod and the side of the box. This compound ring being put on over the end of the piston-rod, another quantity of this rope is to be put upon it, and gently rammed as before; then there is a hollow space left between these two packings, and that space is to be supplied with strong steam from the boiler. Thus is the packing about the piston-rod kept in such a state as to prevent the air from entering the cylinder when at any time there may be a partial vacuum above the piston.

Mr. Hornblower's description of this engine was followed by a mathematical investigation of the principles of its action, by the ingenious professor Robison, which demonstrates that it is the same thing in effect as Mr. Watt's expansion-engine; but though this is true, there is a considerable difference in the steps by which the effect is attained, which gives an important advantage when it is reduced to practice. We shall give an investigation in a more popular form, using only common arithmetic. Mr. Hornblower assumed, that the power or pressure of steam is inversely as the space into which the steam is expanded: this is the case with air, and for the present we will grant it to be so with steam, and reason from the same data as the ingenious inventor gives us.

To explain clearly what passes in the two cylinders, we must deviate from the precise form of the engine, and divest ourselves of one complication of ideas, by reducing both cylinders to the same stroke; therefore, suppose the engine to be made like *fig. 2*, which represents the two cylinders placed one upon the other, the lower one being double the capacity of the upper one, and both pistons being attached to the same rod, which may be applied to the end of the beam, so that the descent of the pistons must draw up the load at the opposite end of the beam.

Then, if we suppose the small piston to be 10 inches in diameter, the great piston must be 14.14 inches; and to avoid all difficulties of the ratio of the expansion, and the pressure of steam, we will suppose the engine to be worked by the pressure of atmospheric air instead of steam; and for the convenience of round numbers in our calculation, we will consider the pressure at only 10 lbs. *per* circular inch on the surface of the piston.

The area of the small piston will be 100 circular inches, and being assumed to move without friction, the pressure upon it will be $10 \times 100 = 1000$ lbs. The area of the great piston is twice as much, or 200 circular inches, and the pressure 2000 lbs.

Suppose both pistons to be at the top of their respective cylinders; let the atmospheric air be admitted to press freely upon the upper surface of the small piston; and sup-

pose the space between the two pistons filled with air of the same density, while there is a perfect vacuum made in the lower part of the great cylinder, beneath its piston.

Under these circumstances, the two pistons will begin to descend with something less than 2000 lbs. of load upon the outer end of the beam, because there are 2000 lbs. of pressure on the great piston by the air contained in the space between the two pistons, bearing on the 200 inches of surface with a weight of 10 lbs. per inch; and beneath this piston there is nothing to counteract the pressure. At the same time, the small piston, having air of equal density above and below it, is in equilibrio.

This force would balance a load of 2000 lbs.; but suppose we diminish the load to 1900 lbs., then the pistons will immediately begin to descend; but they will soon stop, because the air between the two pistons must expand itself, to fill the increasing space occasioned by the equal descent of both pistons in the cylinders, one of which is twice the area of the other; and as the air becomes rarer, its pressure on the great piston must diminish. Now as this same diminution occasions the small piston to have a power of descent, we will first consider the pistons separately, and then conjointly, in their power of descent, with which they draw down the beam.

Descending Power of the Great Piston.

Descending Power of the Small Piston

Combined Power of both Pistons.

	Lbs. 2000		Lbs. 0		Lbs. 2000
At first the power will be		At first the power will be	-	At first	
In consequence of the pressure of 10 lbs. per circular inch upon its upper surface, and no pressure beneath.		Because the piston is in equilibrio, having 1000 lbs. pressing upwards, and 1000 lbs. downwards.			
At one-fourth of the descent, the power will have diminished, by regular decrements, to	1600	At one-fourth, the power will be	200	At one-fourth	1800
Because the air between the two pistons must occupy three-fourths of the small cylinder, and one-fourth of the great cylinder, which is a space equal to one and one-fourth of the original space which it filled; therefore the spaces will be as five to four; and if the density of air is as the inverse proportion of the space which it occupies, the pressure on the great piston must be as four to five, or $\frac{4}{5}$ ths of 2000 = 1600.		Because the equilibrium does not continue, and at one-fourth of the descent the pressure beneath the small piston is reduced by the expansion of the air between the two pistons to four-fifths of 1000 = 800 lbs., while the pressure above the piston continues to be 1000. The power is, therefore, 1000 - 800 = 200.			
At one-half of the descent, the power will have diminished to	1333 $\frac{1}{3}$	At one-half of the descent, the power will have increased to	333 $\frac{1}{3}$	At one-half	1666 $\frac{2}{3}$
Because at this position the air between the pistons occupies one-half of the small cylinder and one-half of the great one, which is a space equal to one and one-half of the space it filled originally. The spaces will therefore be as five to four, and the pressure on the great piston as four to six, or $\frac{2}{3}$ ths of 2000 = 1333 $\frac{1}{3}$.		Because the pressure beneath is diminished by the increased rarity of the air to $\frac{2}{3}$ ths of 1000 = 666 $\frac{2}{3}$, while the downward pressure continues to be 1000. The power is therefore 1000 - 666 $\frac{2}{3}$ = 333 $\frac{1}{3}$.			
At three-fourths of the descent, the power will be only	1142 $\frac{2}{3}$	At three-fourths of the descent, the power will be	428 $\frac{2}{3}$	At three-fourths	1571 $\frac{2}{3}$
Because the air must now occupy one-fourth of the small cylinder, and three-fourths of the large cylinder, which is a space equal to one and three-fourths of the original space. Thus the spaces will be as seven to four, and the pressure on the great piston $\frac{4}{7}$ ths of 2000 = 1142 $\frac{2}{3}$.		Because the pressure beneath is reduced by the rarity of the air to $\frac{1}{2}$ ths of 1000 = 571 $\frac{1}{2}$, therefore the power is 1000 - 571 $\frac{1}{2}$ = 428 $\frac{2}{3}$.			
At the bottom of the cylinder, the power will be	1000	At the bottom, the power will be	500	At the bottom	1500
Because the air must occupy the whole of the large cylinder, a space equal to twice the small cylinder which it at first filled. The pressure will therefore be $\frac{1}{2}$ of 2000.		Because the air beneath the piston is reduced to one-half of its pressure, or 500, which deducted from 1000, leaves 500.			
Sum of the powers exerted by the great piston in its descent	7076	Sum of the powers of the small piston	1461	Sum of the combined powers	

Now let us consider how Mr. Watt's principle of expansion would operate in the same circumstances; that is, in a cylinder of 14.14 inches diameter; which is to be supplied with air of 10 lbs. pressure per circular inch, until it has completed one-half of its descent, and leaving the remainder of the descent to be accomplished by the expansion of the air already contained in the upper half of the cylinder.

	Lbs.
At the beginning, the power of descent will be	2000
At one-fourth, the power will still be	2000
At one-half, the power will be	2000
At three-fourths of the descent, the power will be } diminished to	1333½
Because the air must occupy one-fourth of the length of the cylinder, in addition to that half of the cylinder which it occupied before the expansion began; therefore the space is one and a half times the former, or as three to two, and the pressure will be two-thirds of 2000.	
At the bottom the pressure will be	1000
Because the air is expanded to occupy twice the space it filled before.	

8333½

The sum total is very nearly the same as the former, but both are greater than they should be, from the imperfect manner in which we have been obliged to make our calculation, so as to express it in common arithmetic, without having recourse to fluxions, which is the only method of treating quantities that are constantly increasing or decreasing by any given law.

The source of the inaccuracy is easily explained: at first we set out with the pressure at 2000 lbs. in Mr. Hornblower's engine, and did not take into the account that it decreases at all, until the piston has descended to one-fourth, but reasoned as though it diminished all at once at that place; whereas it began to diminish from the very first starting. Here then we have taken a small quantity too much. In the same manner, our process takes no notice of the diminution which happens between one-fourth and one-half of the descent, or between the other points at which we have chosen to examine it; the result is, as if the diminution took place suddenly at each of those points. The remedy for this would have been to have taken the account at a greater number of places, as it is by fluxions alone that we can take an infinite number, so as to obtain a true result. Now in the second calculation of Mr. Watt's expansion-engine, we have taken a still less number of steps for the consideration of the expansion, because, although there are four steps in the process, two of them are before the expansion begins.

This is the reason of the apparent difference; for in reality there is none in the sum total of the varying powers exerted through the whole stroke, as will appear to any person who will take the trouble to read professor Robison's investigation. But if we consider the difference of the manner in which the whole power is expended during the stroke, we shall see great reason to prefer Mr. Hornblower's method, from the much greater uniformity of the action; it begins at 2000, and ends at 1500; whilst Mr. Watt's begins at 2000, and ends at 1000: hence the necessity of those ingenious contrivances for equalizing the action in Mr. Watt's patent of 1782. Mr. Hornblower's is not uniform, but approaches uniformity more nearly, so that he could have carried the effect of the expansive principle much farther, in employing stronger steam, than we believe he ever proposed to do.

We have been thus full upon this subject, because the gaining more power by the expansion of air or steam acting

in double cylinders, has been a favourite idea with many, and there are no less than five different patents for it, but several of these have been upon mistaken notions; neither Mr. Watt's nor Mr. Hornblower's can have any advantage from shutting off the air, or from a double cylinder, when air is used to press the piston; nor could they derive any advantage from the expansion of steam in their engines, if the pressure of it was inversely as the space it occupies.

The advantage of the expansive principle arises wholly from a peculiar property of steam, by which, when suffered to expand itself to fill a greater space, it decreases in pressure or elastic force by a certain law, which is not fully laid down; that is, the relation between its expansive force and the space which it occupies is not clearly decided: but Mr. Woolf has found that, by applying these properties in their fullest extent to the double cylinder engine, he can make most important improvements in the effects which can be obtained from any given quantity of fuel. Steam is a fluid so different from air, as to have no one property in common with it, except elasticity. This elasticity is wholly derived from the quantity of heat which it contains, and its force increases and diminishes with the quantity of heat; but by what law it increases or diminishes we are uncertain, because we have no measure of the actual quantity of heat which is contained in steam of any given elastic force. All we know with certainty is what is stated in our table of expansion, viz. that water, being converted into steam, and confined in a close vessel, when heated until the thermometer indicates a certain temperature, will have a certain pressure or elastic force. But here we must observe, that the thermometer indicates only the intensity of the heat, without affording a direct measure of its quantity. When steam is suffered to expand itself into any given space, the quantity of rarefied water which will be found to be contained in any given bulk of steam, in its expanded state, must be undoubtedly proportioned to the quantity of water contained in the same bulk of the steam, before the expansion took place, in the inverse ratio of the space which it originally occupied, and that space which it fills when expanded; but we cannot say that this is the case with heat; and it is the quantity of heat alone which determines the elastic force.

We believe that in practice Mr. Hornblower was not able to obtain any greater effect from the application of the expansive action in two cylinders, than Mr. Watt did in one cylinder. In 1791-2, he erected an engine in Cornwall, at Tin-Croft mine, of which the large cylinder was 27 inches diameter, and worked with a stroke of eight feet long, and the small cylinder 21 inches diameter, working with a six-foot stroke. The only account we have been able to obtain of the performance of this engine, is from a pamphlet published by Thomas Wilson, an agent of Messrs. Boulton and Watt, professedly with a view to prevent the introduction of Mr. Hornblower's engines into that country, in which he makes it appear, that it raised only 14,222,120 lbs. of water one foot high with each bushel of coals.

In Mr. Hornblower's own account of his engine, in Gregory's Mechanics, he informs us, that "an engine was erected in the vicinity of Bath, some years since, on this principle, and under very disadvantageous circumstances. The engine had its cylinders 19 inches and 24 inches diameter, with lengths of stroke in each suitable to the occasion: viz. 6 feet and 8 feet respectively. The condensing apparatus was very bad, through a fear of infringement on Mr. Watt's patent; and the greatest degree

of vacuum which could be obtained, was no more than 27 inches of mercury. The engine worked four lifts of pumps to the depth of 576 feet, 4500 lbs. 14 strokes in a minute, 6 feet each, with a cylinder 6 feet long, and 19 inches diameter, with a great deal of inertia and friction in the rods and buckets; some of the latter of which were not more than $3\frac{1}{2}$ inches diameter: and this it did, under all these disadvantageous circumstances, with 70 lbs. of coal (light coal) *per hour*."

To reduce this to the standard of one foot high, we must put the load 4500 lbs. \times 6-foot stroke = 27,000 lbs. which the engine raised one foot high at every stroke; 27,000 lbs. \times 14 strokes *per minute* = 378,000 lbs. raised one foot high each minute; 378,000 lbs. \times 60 = 22,680,000 lbs. raised one foot high *per hour*, or with 70 lbs. of coals. As the coals are stated to be light, we will take them at only 84 lbs. *per bushel*, instead of 88 lbs., as Mr. Smeaton did, and say as 70 lbs.: 22,680,000 lbs. :: 84 lbs.: 27,216,000 lbs. of water raised one foot high with a bushel of coals, which is a very good performance, but not greater than Mr. Watt's.

In this engine, Mr. Hornblower says that two remarkable circumstances presented themselves to shew the advantages of this application of the principle: the one was, that the man who attended the engine would sometimes detach the smaller cylinder from the beam, and work only with the large one, and then the boiler would scarcely raise steam enough to keep the engine going; but no sooner was the small cylinder-rod attached to the beam, than the engine resumed its wonted activity, and the steam would blow up the safety-valve.

The next circumstance is, that when the detent, which kept the exhausting-valve shut, happened to miss its action, the piston would be checked, as it were, not being permitted to rise through the whole of the returning stroke; and it would, as by an instructive nature, come down again and again, until the detent performed its office, which is a practical argument for the power of the engine at the termination of its stroke.

In 1792, Mr. Hornblower made application to parliament for an extension of the term of his patent, but it was not granted: and he was prosecuted by Messrs. Boulton and Watt for infringement on their patent in using the condenser and air-pump. We believe none of these engines have been erected since the expiration of Mr. Watt's patent in 1800, until Mr. Woolf took up the subject of double-cylinder engines.

Mr. Woolf's Double-Cylinder Expansion-Engine.—In 1804

Mr. Arthur Woolf had a patent for improvements in steam-engines. The specification of his invention states, that he has ascertained by actual experiment, and reduced to practice, the following particulars respecting the expansibility of steam. That, in practice it is found that steam, acting with the expansive force of four pounds pressure *per square inch* against a safety-valve exposed to the atmosphere, is capable of expanding itself to four times the volume it then occupies, and still to be equal to the pressure of the atmosphere: that, in like manner, steam of the force of five pounds the square inch, can expand itself to five times its volume; and that masses or quantities of steam of the like expansive force of six, seven, eight, nine, or ten pounds pressure *per square inch*, can expand to six, seven, eight, nine, or ten times their volume, and still be respectively equal to the atmosphere, or capable of producing a sufficient action against the piston of a steam-engine, to cause the same to rise in the atmospheric engine of Newcomen with a counterpoise, or to be carried into the vacuum part of the cylinder of the improved engine, first brought into effect by Mr. Watt: that this ratio is progressive, and nearly, if not entirely, uniform; so that steam pressing with the expansive force of 20, 30, 40, or 50 pounds the square inch against a common safety-valve, will expand itself to 20, 30, 40, or 50 times its volume; and that, generally, as to all the intermediate or higher degrees of elastic force, the number of times which steam of any temperature and force can expand itself, is nearly the same as the number of pounds it is able to sustain on a square inch exposed to the common atmospheric counter-pressure; provided always, that the space, place, or vessel, in which it is allowed to expand itself, be kept at the same temperature as that of the steam, before it is allowed room to expand.

Respecting the different degrees of temperature required to bring steam to, and maintain it at, different expansive forces above the weight of the atmosphere, Mr. Woolf states that he has found by actual experiment, setting out from the boiling point of water, or 212° of Fahrenheit, at which degree steam of water is only equal to the pressure of the atmosphere; that, in order to give an increased elastic force equal to five pounds on each square inch, the temperature must be raised to about $227\frac{1}{2}^{\circ}$, when it will have acquired a power to expand itself to five times its volume, and still be equal to the atmosphere, and capable of being applied as such in the working of steam-engines, according to his invention. Various other pressures, temperatures, and expansive forces of steam, are shewn in the following table.

Woolf's Table of the relative Pressures *per square Inch*: the Temperature and Expansibility of Steam at Degrees of Heat above the boiling Point of Water, beginning with the Temperature of Steam of an elastic Force equal to five Pounds *per square Inch*; and extending to Steam able to sustain forty Pounds on the square Inch.

Pounds per square Inch.	Degrees of Heat.		
	227 $\frac{1}{2}$	5	
	230 $\frac{1}{2}$	6	
	232 $\frac{1}{2}$	7	
	235 $\frac{1}{2}$	8	
Steam of an elastic force predominating over the pressure of the atmosphere upon a safety-valve	237 $\frac{1}{2}$	9	and, at these respective degrees of heat, steam can expand itself to about
	239 $\frac{1}{2}$	10	
	250 $\frac{1}{2}$	15	
	259 $\frac{1}{2}$	20	
	267	25	
	273	30	
	278	35	
	282	40	

requires to be maintained by a temperature equal to about

times its volume, and continue equal in elasticity to the pressure of the atmosphere.

And so in like manner, by small additions of temperature, an expansive power may be given to steam to enable it to expand to 50, 60, 70, 80, 90, 100, 200, 300, or more times its volume, without any limitation but what is imposed by the frangible nature of every material of which boilers and other parts of steam-engines can be made. And prudence dictates, that the expansive force should never be carried to the utmost which the materials can bear, but rather be kept considerably within that limit.

Having thus explained the nature of his discovery, Mr. Woolf proceeds to give a description of his improvements grounded thereon.

If the engine is constructed originally with the intention of adopting these improvements, it ought to have two steam-cylinders of different dimensions, and proportioned to each other, according to the temperature, or the expansive force determined to be communicated to the steam made use of in working the engine; for the smaller steam-vessel or cylinder must be a guide for the larger. For example; if steam of forty pounds the square inch is fixed on, then the smaller cylinder should be at least one-fortieth part the contents of the larger one. Each cylinder should be furnished with a piston, and the smaller cylinder should have a communication, both at its top and bottom, (top and bottom being here employed merely as relative terms, for the cylinders may be worked in a horizontal, or any other required position, as well as vertical,) with the boiler which supplies the steam; and the communications, by means of cocks or valves of any construction adapted to the use, are to be alternately opened and shut during the working of the engine. The top of the small cylinder should have a communication with the bottom of the larger cylinder, and the bottom of the smaller one with the top of the larger, with proper means to open and shut these alternately by cocks, valves, or any other well-known contrivance. And both the top and bottom of the larger cylinder should, while the engine is at work, communicate alternately with a condensing vessel, into which a jet of water is admitted to hasten the condensation; or the condensing vessel may be cooled by any other means calculated to produce that effect.

Things being thus arranged, when the engine is set to work, steam of a high temperature is admitted from the boiler to act by its elastic force on one side of the smaller piston, while the steam which had last moved it has a communication with the larger steam-vessel or cylinder, where it follows the larger piston, now moving towards that end of its cylinder which is open to the condensing vessel. Let both pistons end their stroke at one time, and let us now suppose them both at the top of their respective cylinders, ready to descend; then the steam of forty pounds the square inch, entering above the smaller piston, will carry it downwards; while the steam below it, instead of being allowed to escape into the atmosphere, or applied to any other purpose, will pass into the larger cylinder above its piston, which will make its downward stroke at the same time that the piston of the smaller cylinder is doing the same thing; and while this goes on, the steam which last filled the larger cylinder in the upward stroke of the engine will be passing into the condenser, to be condensed during the downward stroke. When the pistons in the smaller and larger cylinder have thus been made to descend to the bottom of their respective cylinders, then the steam from the boiler is to be shut off from the top, and admitted to the bottom of the smaller cylinder. The communication between the bottom of the smaller and the top of the larger cylinder is also to be cut off; and the communication is to be opened between the top of the smaller and the bottom of the larger cylinder. The communication

between the bottom of the larger cylinder and the condenser is to be cut off, and the steam which, in the downward stroke of the engine, filled the upper part of the larger cylinder, suffered to flow off to the condenser. The engine will then make its upward stroke from the pressure of the steam in the top of the small cylinder, acting beneath the piston of the great cylinder, and so on alternately, admitting the steam to the different sides of the smaller piston, while the steam last admitted into the smaller cylinder passes alternately to the different sides of the larger piston in the larger cylinders; the top and bottom of which are at the same time made to communicate alternately with the condenser.

In an engine working in the manner just described, while the steam is admitted on one side of the piston into the smaller cylinder, the steam on the other side has room made for its admission into the larger cylinder, on one side of its piston, by the condensation taking place on the other side of the large piston which is open to the condenser; and that waste of steam which takes place in engines worked only by the expansive force of steam, from steam passing the piston, is prevented; for all steam that passes the piston in the smaller cylinder is received into the larger.

In such an engine, where it may be more convenient for any particular purpose, the arrangement may be altered, and the top of the smaller made to communicate with the top of the larger cylinder; in which case the only difference will be, that when the piston in the smaller cylinder descends, that in the larger will ascend, and *vice versa*; which, on some occasions, may be more convenient than to have the two pistons moving in the same direction.

This engine is exactly the same in its action as Mr. Hornblower's, which we have before described. The novelty, consists in the application of steam of a high pressure thereto, and in proportioning the capacities of the two cylinders to the expansibility of the steam, according to his table. But Mr. W. goes on to state, that effectual means must be used to keep up the requisite temperature in all parts of the apparatus into which the steam is admitted, and in which it is not intended to be condensed; and here it may be proper to state, that instead of the usual means of accomplishing this, by inclosing them in the boiler, or in a steam-case communicating with the boiler, a separate fire may with advantage be made under the steam-case containing the cylinders, which in that event will become a second boiler, and must be furnished with a safety valve, to regulate the temperature. By means of the last-mentioned arrangement, the steam from the smaller cylinder or steam-measurer may be admitted into the larger cylinder, when kept at a higher temperature than the steam in the smaller cylinder, by which its power to expand itself may be increased; and, on the contrary, by keeping the larger cylinder at a lower temperature than the smaller, its expansibility will be lessened, which, on particular occasions, and for particular purposes, may be desirable. In every case, care must be taken that the boiler, or case in which the cylinder is inclosed, the steam-pipes, and generally all the parts exposed to the action of the expansive force of the steam, shall have a strength proportioned to the high pressure to which they are to be exposed.

It is not advisable that the proportion of the capacity of the smaller cylinder or steam-measurer, to the capacity of the larger or working cylinder, should in any case be smaller than the proportion of the expansion of the steam which is to be used in it, as we have stated; yet in the making of it larger, considerable latitude may be allowed; for example, with steam of forty pounds the square inch, a small cylinder or measurer of one-twentieth, or even larger, instead of one of fortieth the capacity of the larger or working cylinder.

der, and so with steam of any given strength. And in many cases, it may be advisable that this should be the case, because of the difficulty of preventing some waste of steam, or partial condensation, which might lessen the rate of working, if not allowed for in the size of the small cylinder or steam-measurer.

In all cases when the engine is ready for working, whatever may be the proportion that has been adopted, or intended to be worked with, it should have its power tried by altering the load on the valve that ascertains the force of the steam, in order that the strength of steam best adapted for the engine may be ascertained, for it may turn out to be advantageous, that the steam should be employed in particular engines of an elastic force, somewhat over or under what was first intended.

Mr. Woolf also states, that Mr. Watt's engines may be improved by the application of his discovery in making the boiler, and the steam-cake in which the working cylinder is inclosed, much stronger than usual, and by altering the structure and dimensions of the valves for admitting steam from the boiler into the cylinder in such a manner, that the steam may be admitted very gradually by a progressive enlargement of the aperture, so as at first to wire-draw the steam, and afterwards to admit it more freely. The reason of this precaution is this, that steam of such elastic force as Mr. Woolf proposes to employ, if admitted suddenly into the cylinder, would strike the piston with a force that would endanger the safety and durability of the engine. The aperture allowed to the valve for admitting steam into the cylinder, or cylinders, should be regulated by the following consideration. If the intention is, that the engine should work wholly, or almost wholly, by condensation, the steam, in passing into the cylinder, should be forced to wire-draw itself only so much, that the piston may perform the whole, or a great part of the stroke, by the time that the intended quantity of steam has been admitted into the cylinder. For example, when steam of forty pounds on the square inch is used, such a quantity of it must be allowed to enter as shall be equal to one-fortieth of the capacity of the cylinder, and so in proportion when steam of any other force is employed; and when the requisite quantity has been admitted, the steam is to be shut off till the proper moment for admitting a fresh quantity. But if it is intended that advantage shall also be taken of the elastic force of the steam acting on one side of the piston, while condensation goes on on the other side, then the steam must be admitted more freely, but still with caution at first, for the reason already mentioned.

This latter is the same thing as Mr. Watt's expansion-engine; but with the addition of gradually diminishing the aperture of the steam-valve as the piston descends, instead of stopping it altogether at a certain portion of the descent, by which means the action of the engine is rendered more uniform. We think that, by regulating the descent of the valve by an accurate movement, a very good effect may be produced in this manner, without the complication of two cylinders or other parts; the only objection is, that if at any time the valve should be fully opened by accident, the pressure might suddenly become so great, from the strong steam acting upon the full surface of the piston, as to break the engine to pieces.

In 1805, Mr. Woolf took out a second patent for further improvements, in which he proposes, as before, to apply fire to the cylinder itself, to heat the steam after it is thrown into the working cylinder; and this was to be done by a fire being placed beneath the case containing the cylinder: the space between the case and the cylinder was to be filled

with oil, wax, fusible metal, or mercury. He also proposes a method of preventing the passage of any of the steam from that side of the piston which is acted upon by the steam, to the other side, which is open to the condenser. In those steam-engines which act as double engines, he effects this by employing upon, or about the piston, a column of mercury, or fluid metals, in an altitude equal to the pressure of the steam. The efficacy of this arrangement will, he says, appear obvious, from attending to what takes place in the working of such a piston. When the piston is ascending, that is, when the steam is admitted below it, the space on its upper side being open to the condenser, the steam, endeavouring to pass up by the side of the piston, is met, and effectually prevented by the column of metal, equal or superior to it in pressure; and during the down stroke no steam can possibly pass without first forcing all the metal through.

In working what is called a single engine, a less considerable altitude of metal is required, because the steam always acts on the upper side of the piston; and in this case, oil or wax, or fat of animals, or similar substances in sufficient quantity, will answer the purpose. But care must be taken, either in the double or single engine, when working with this piston, that the outlet which conveys the steam to the condenser shall be so situated, and of such a size, that the steam may pass freely, without forcing before it, or carrying with it, any of the metal, or other substance employed, that may have passed by the piston; and at the same time providing another exit for the metal, or other substance collected at the bottom of the cylinder to convey the same into a reservoir kept at a proper heat, whence it is to be returned to the upper side of the piston by a small pump, worked by the engine, or by some other contrivance. In order that the fluid metal used with the piston may not be oxydated, some oil or other fluid substance is always to be kept on its surface, to prevent its coming in contact with the steam: and to prevent the necessity of employing a large quantity of fluid metal, although the piston must be as thick as the depth of the column required, the diameter need be only a little less than the steam-vessel, or working cylinder, excepting where the packing, or other fitting, is necessary to be applied; so that, in fact, the column of fluid metal forms only a thin body round the piston.

We have seen an engine of an eight-horse power of this kind at work, with a fluid metal on the pistons: it effectually prevented the leakage. But as it required to have the cylinders twice as long as usual, in order to have sufficient room for the long or thick pistons which it required, and as these pistons must be of considerable weight, the method is not at all applicable in practice; and, indeed, the increase of the bulk of the moving parts is such as to counterbalance the advantage, which is confined to the saving of steam by leakage: for the friction must be greater than in another engine, because the piston must be packed as tight as usual, to be able to sustain a column of fluid metal, which must be more than equal in pressure to that of the steam; and when the steam presses upon the piston, the pressure of the fluid metal to leak by the piston must be double that of the steam: also, the friction of so great a surface of fluid metal pressing against the inside of the cylinder is very great.

In 1810, Mr. Woolf had a third patent, the object of which is to prevent the waste of steam, from leakage by the piston. For this purpose, he does not allow the steam to come to the piston at all, but causes it to act in a different vessel, and transmits the action thereof to the piston by oil or fluid metal: thus, at the side of the

cylinder, he places a separate vessel, communicating with the lower part of the cylinder by a large pipe or passage from the bottom of each; then steam, being admitted into this vessel, will press upon the surface of the oil or fluid metal contained in it, and force the same to pass out of that vessel into the cylinder, where it will act beneath the piston to press the same upwards; a vacuum being at the same time made in the upper part of the cylinder, to give effect to the pressure. The steam is then made to press upon the upper surface of the piston, which is always covered with a quantity of the fluid; and at the same time a vacuum is made in the separate vessel, so as to relieve the surface thereof from all pressure: in consequence, the piston is made to descend. It is evident that the piston must be packed so tight as to suffer none of the fluid to pass by it; but this is easy, in comparison with the difficulty of making a packing sufficiently tight to resist the passage of steam, particularly when it is so rare as the expanded steam which Mr. Woolf sometimes uses in his engine. The separate vessel of which we have spoken, is in some cases to be the jacket or space which surrounds the cylinder, which is then to be open at bottom.

This contrivance is ingenious, but we think the necessity of an additional cylinder is an objection which will prevent its adoption in large engines; and for small engines the advantages are not so great.

Performance of Mr. Woolf's Engines.—Since his first patent, Mr. Woolf has erected several small engines, which performed well, and with an evident economy of fuel. But these engines being employed to turn mills, of which the operations do not afford so exact an estimate of the power as the operation of pumping water, Mr. Woolf's engines did not come to a direct and indisputable comparison with those on Mr. Watt's principle, until 1815, when two large engines were set to work in Cornwall, at Wheal Vor and Wheal Abraham mines, for pumping water; and these have since been regularly reported in Messrs. T. and J. Leans reports, of which we have before spoken, and of which one of the objects was to ascertain the comparative merit of the double and single cylinder engines.

The report for May, 1815, states the average performance of these two engines at 49,980,882 lbs. lifted one foot high for each bushel of coal; and since that time they have done more than 50,000,000 lbs.

The engine at Wheal Vor has a great cylinder of 53 inches diameter, and 9-feet stroke; and the small cylinder is about one-fifth of the contents of the great one. The engine works six pumps, which, at every stroke, raise a load of water of 37,982 lbs. weight $7\frac{1}{2}$ feet high, which is the length of the stroke in the pumps. This makes a pressure of 14.1 lbs. per square inch on the surface of the great piston, and it makes 7.6 strokes per minute. With respect to its consumption of coals, it raised, in March, 1816, 48,432,702 lbs. one foot high with each bushel; April, 1816, 44,000,000 lbs.; May, 1816, 49,500,000 lbs.; and in June, 1816, 43,000,000 lbs.

From the same reports we learn, that the engine at Wheal Abraham mine has a great cylinder of 45 inches diameter, working with a 7-feet stroke, at the rate of 8.4 strokes per minute, under a load of 24,050 lbs., which it raises 7 feet at each stroke. Its performance during the above four months was 50,000,000 lbs.; 50,908,000 lbs.; in May, 56,917,312 lbs., which, we believe, is the greatest performance ever made by a steam-engine; and in June, 51,500,000 lbs.

We have before given a similar account of Mr. Watt's engines; but at the same time we must observe, that the

variation in the performance of different steam-engines, which are constructed upon the same principle, and working under the same advantages, is the same as would be found in the produce of the labour of so many different horses, or other animals, when compared with their consumptive food; for the effects of different steam-engines will vary as much from small differences in the proportions of their parts, as the strength of animals from the vigour of their constitution: and, again, there will be as great differences in the performance of the same engine, when in bad or good order, from all the parts being tight and well oiled, so as to move with little friction, as there is in the labour of an animal, from his being in good or bad health, or excessively fatigued; but, in all cases, there will be a maximum which cannot be exceeded, and an average which we ought always expect to attain.

Plate V. fig. 3. is a sketch to shew the arrangement of the valves and cylinders of these two engines: A is the large cylinder, and B the little cylinder, each inclosed in its steam-case. The steam is admitted from the boiler into the steam-case of the large cylinder A, by a communication at C; and there is a communication between this steam-case and that of the small cylinder; so that all the steam for the supply of the engine passes through both of the steam-cases, which therefore become part of the communication between the boiler and the little cylinder, into which the steam is first admitted. D furnishes a communication for carrying back to the boiler any water which may be produced by condensation in the steam-case, before the engine is heated to the proper temperature. E is the pipe from the steam-case to supply the engine; it has a regulating-valve. F is the valve-box of the small cylinder, the spindle of the one valve working through that of the other; and the passage for the steam from the case into the small cylinder is situated between the two valves. G is the valve that opens the communication between the bottom of the small cylinder B, and the top of the large cylinder A, when the piston thereof is to be pressed down. H is the valve that returns the steam from above to below the large piston, when the piston is to ascend. And I is the exhaustion-valve, to carry off the steam to the condenser.

When the engine makes its down-stroke, the upper valve at F is opened, and admits the steam from the case to press upon the small piston, the valve G being opened at the same time, which suffers the steam to pass from the under side of the small to the upper side of the large piston; and the valve I is opened to make a passage from beneath the great piston to the condenser. These three upper valves, F, G, I, open at the same instant of time.

When both pistons arrive at the bottom of their respective cylinders, these three valves are shut all together, and the lower steam-valve at F is opened, to return the steam from above to below the small piston; the valve H doing the same to the large cylinder, and both pistons return in equilibrio by the counter-weight; but the upper valve at F can be shut off at any part of the stroke, according to the load of the engine.

Those who are conversant with steam-engines will perceive, from the passing of the steam, as above described, from the upper to the lower side of each of the pistons respectively, that the engines at Wheal Vor, and at Wheal Abraham, are at present working with a single stroke. Were these engines working double, the steam would, on the down-stroke, be made to pass, the same as before described, from the under side of the small, to the upper side of the large piston, steam from the boiler in the mean time coming in upon the small piston, and the under side of the large piston being open to the

condenser; but on the up-stroke, the action would be different from what we have described, for the steam would pass from the top of the small cylinder to beneath the large piston, while steam would be admitted from the boiler under the small piston, the top of the large cylinder being open to the condenser.

Mr. Woolf's Boiler for raising Steam of a high Pressure with Safety.—The boilers which Mr. Woolf employs in his engines are different from those of other engines which work with steam of a low pressure, the water being contained in several cylindrical tubes of cast-iron, which are filled with water, and exposed to the flame nearly in an horizontal position.

Mr. Woolf has a patent for this boiler, which the specification states to consist of two or more cylindrical vessels, properly connected together, and so disposed, as to constitute a strong and fit receptacle for the water intended to be converted into steam of a temperature and under a pressure uncommonly high, and also to present an extensive portion of convex surface to the current of flame and heated air from a fire; likewise of other large cylindrical receptacles placed above the former cylinders, and properly connected with them, for the purpose of containing some water and the steam.

These cylindrical vessels are set in a furnace so adapted to them, as to cause the greater part of the surface of each of them, or as much of the surface as may be convenient, to receive the direct action of the fire, or heated air or flame.

Plate V. figs. 4 and 5, represents one of these boilers in its most simple form. It consists of eight tubes, marked *a*, made of cast-iron, or any other fit metal, which are each connected with the larger cylinder *A*, placed above them, as is shewn in the side view, *fig. 5*, in which the same letters refer to the same parts as in *fig. 4*. In *fig. 5*, is also shewn the manner in which the fire is made to act. The fuel rests on the grate-bars at *B*, and the flame and heated air, being reverberated from the part above the two first smaller cylinders, go under the third, over the fourth, under the fifth, over the sixth, under the seventh, and partly over and partly under the eighth small cylindric tube, all which tubes are full of water. The direction of the flame, until it reaches the last-mentioned tube, is shewn by the dotted curved lines and arrows. When it has reached that end of the furnace, it is carried by the flue, *O*, to the other side of a wall, built beneath the main cylinder *A*, in the direction of its length, and the flame then returns under the opposite end of the seventh smaller cylinder over the sixth, under the fifth, over the fourth, under the third, over the second, and partly over and partly under the first, when it passes into the chimney. The wall before-mentioned, which divides the furnace longitudinally, answers the double purpose of lengthening the course which the flame and heated air have to traverse, giving off heat to the boiler in the passage, and also of securing the flanges, or other joinings, employed to unite the smaller tubes to the main cylinder, from being injured by the fire. The ends of the small cylindric tubes rest on the brick-work which forms the sides of the furnace, and one end of each of them is furnished with a cover, secured in its place by screws and a flanch, but which can be taken off at pleasure, to allow the tubes to be cleared, from time to time, from any incrustation or sediment which may be deposited in them.

To any convenient part of the main cylinder, *A*, a tube is affixed, to convey the steam to the steam-engine. In working with such boilers, the water carried off by evapo-

ration is replaced by water forced in by the usual means of a high-pressure boiler, that is, a forcing-pump; and the steam generated is carried to the place intended by means of pipes connected with the upper part of the cylinder *A*. In the specification, means are pointed out for applying this plan to the boilers of steam-engines already in use, by ranging a row of cylinders beneath the present boiler, and connecting them with each other, and with the boiler. Directions are also given for constructing boilers composed of cylinders disposed vertically. In every case the tubes composing the boiler should be so combined and arranged, and the furnace so constructed, as to make the fire and flame act around and over the tubes, so as to embrace the largest possible quantity of their surface. It must be obvious to any one, that the tubes may be made of any kind of metal; but cast-iron is the most convenient. The size of the tubes may be varied; but in every case, care should be taken not to make the diameter too great: for it must be remembered, that the larger the diameter of any single tube is in such a boiler, the stronger it must be made in proportion, to enable it to bear the same expansive force of steam as the smaller cylinders. It is not essential, however, to the invention, that the tubes should be of different sizes; but the upper cylinders, especially the one which is called the steam-cylinder, should be larger than the lower ones, it being the reservoir, as it were, into which the lower ones send the steam, to be thence conveyed away by the steam-pipe. The following general directions are given respecting the quantity of water to be kept in a boiler of this construction; viz. it ought always to fill, not only the whole of the lower tubes, but also the great steam-cylinder *A*, to about half its diameter, that is, as high as the fire is allowed to reach; and in no case should it be allowed to get so low, as not to keep the vertical necks, or branches, which join the smaller cylinders to the great cylinder, full of water, for the fire is only beneficially employed when applied, through the medium of the interposed metal, to water, to convert it into steam; that is, the purpose of the boiler would in some measure be defeated, if any of the parts of the tubes which are exposed to the direct action of the fire, should present a surface of steam in their interior, instead of water, to receive the transmitted heat. This must, more or less, be the case, whenever the lower tubes, and even a part of the upper, are not kept filled with the water.

Respecting the furnace for this kind of boiler, it should always be so built as to give a long and waving course to the flame and heated air, forcing them the more effectually to strike against the sides of the tubes which compose the boiler, and so to give out the greatest possible portion of their heat before they reach the chimney. Unless this be attended to, there will be a much greater waste of fuel than necessary, and the heat communicated to the contents of the boiler will be less from a given quantity of fuel.

When very high temperatures are not to be employed, the kind of boiler just described is found to answer very well; but where the utmost force of the fire is desirable for producing the most elastic steam, the parts are combined in a manner somewhat different, though the principle is the same. In the *Philosophical Magazine*, vol. xvii. p. 40, are a description and drawing of a boiler of this kind, two of which were erected in 1803 at Messrs. Meux's brewery.

In every case Mr. Woolf uses two safety-valves, at least, in his apparatus, to prevent accidents; a precaution which cannot be too strongly enforced, as it may happen, when

but one is employed, that by some accident it may get locked, and the engine and people about it be exposed to the danger of an explosion.

In those engines of Mr. Woolf's which we have seen, he employs boilers like the one described, *viz.* with two small tubes beneath, which are full of water, and exposed to the immediate action of the flame, communicating by perpendicular necks or branches with the large cylinder above, which has water in the lower part, and steam in the upper. The only difference from what we have above described is, that the lower and upper tubes are placed in the same direction, instead of being at right angles to each other; and the flame proceeds in the direction of their length, instead of crossing them; the lower or water tubes are rather inclined upwards. The metal of these tubes is made very thick, with a view to strength and durability.

The idea of making boilers for raising strong steam, by a number of small tubes, which can be made stronger than one large vessel, is not original with Mr. Woolf; Mr. Blakey, of whom we have before spoken, having proposed it in a small tract which he published in French, at the Hague, in 1776. But his tubes were to be placed over each other, in an inclined direction; and the water being admitted at the upper end, ran down within the heated inclined tubes, and became converted into steam.

Woolf's Regulating Steam-Valve.—Besides the common safety-valves, Mr. Woolf has also introduced a valve of a new construction into the steam-pipe itself, to regulate the quantity that shall pass from the boiler. In fact, it is a self-acting steam-regulator, and extremely ingenious. A (*fig. 6.*) is a part of the great or steam cylinder of one of Mr. Woolf's boilers; BB, the neck or outlet for the steam, furnished by a steam-box C, which is joined to the neck BB, by the flanges *a, a*. The top or cover of the steam-box C, marked with the letter D, is well secured in its place, and has a hole through it for the rod of the valve to pass; and the interior of the hole is formed to a box to hold a stuffing, and make the rod work up and down steam-tight; the stuffing being kept in its place by means of a collar, screwed down in the usual way, as shewn in the figure. By means of a pin *b*, and the two vertical pieces *e, e*, the sliding-valve rod is made fast to *m*, which is a close cover to the hollow cylinder *nn*. The cover, *m*, fits steam-tight into the conical seat, at the upper end of a collar *oo*, which is made fast to the flange *a, a*, and descends into the neck of the boiler, forming a barrel, in which the cylinder fits close. The cylinder, *nn*, is open at bottom, having a free communication with the steam in the boiler A; and it has three vertical slits cut through the sides, one of which, S, is shewn in the plate. The sum of the area of all these slits or openings is equal to the area of the opening of the seat or collar *oo*, in which the cylinder, *nn*, works.

When the steam acquires a sufficient degree of elastic force to raise the valve, (that is, the cylinder *nn*, with its cover *m*, and the rod R,) together with whatever weight the rod may be loaded, then the openings S, rising above the steam-tight collar or seat *oo*, allow the steam to pass into the steam-box C, and to flow off to the engine through the pipe N. But the quantity of steam that passes is proportioned to the elastic force it has acquired, and the weight with which the valve is loaded; because the rise of the openings, S, above the collar *oo*, will be in that proportion.

This valve may be loaded by applying weights in any of the usual methods; but Mr. Woolf prefers the one shewn

in the drawing, in which the upper part of the rod, R, is joined by means of a chain to a quadrant of a circle Q, with an arm projecting from it, as represented in the plate, for the purpose of carrying a pendulum weight Z, that admits of being moved nearer to or farther from the centre of the quadrant, according as the pressure of the valve is wished to be increased or diminished.

As the valve rises, the weight moves upwards in the arc *nn*, giving a continually increased resistance to the farther rising of the valve, proportioned to the horizontal distance of the weight from the centre of Q, of which the weight attains a continual increase by its rise in the arc, according to the horizontal distances measured on the line Q*p*, passing through the centre of the weight by perpendiculars from the horizontal line.

Thus, if the weight Z presses down the valve *m*, with a force equal to 20 lbs. on the square inch of the aperture in *oo*, in its present position, when it rises to the position at *i*, it will press with a force equal to 30 lbs.; and at *p*, with a force equal to 40 lbs. on the square inch; so that the rod, Z, may be made to serve at the same time as an index to the person who attends the fire, nothing more being necessary for this purpose than to graduate the arc described by the end of the rod QZ, by experimental trials. In the side of the steam-box C, there is an opening N, to allow the steam to pass from it by a pipe to the steam-engine.

It is plain that the adjustment of the positive pressure on this valve can be determined by sliding the weight, Z, of the pendulum to a greater or less distance from the centre of motion. Again, to adjust the rate of the increasing forces, so as to correspond with the increasing force of the steam, the radius of the quadrant, Q, must be apportioned to the diameter of the valve, and the opening of the slits S, so that the ascent of the weight, Z, in its quadrant will be correspondent to the varying pressure. This adjustment must be made as nearly as it can be done before the valve is fixed; and to bring it afterwards to an exact regulation, the chain is attached to the rod, R, by a nut and screw; by means of which, any part of the arc can be used that is found most correspondent with the varying pressure, because the rate at which the resistance of the lever increases is more rapid when the pendulum is near to the perpendicular, than when it approaches the horizontal position.

The same effect may be produced, by making the slits in the side of the cylinder narrower at the lower part of the cylinder, instead of being parallel.

Edelcrantz's Safety-Valve.—The chevalier Edelcrantz contrived a safety-valve, some years ago, which has the same properties as Mr. Woolf's, and is worthy of notice, as being more simple in its construction. A small brass cylinder is fixed on the boiler, and fitted with a piston, which moves with very little friction, in order that it may descend by its own weight, after it has been raised up, without, however, permitting the steam to pass between it and the cylinder in any quantity. The lower part of the cylinder communicates with the boiler, and the upper part is closed by a small cover screwed on to it, and perforated with a hole, through which the piston-rod passes easily. This cover serves the double purpose of guiding the rod, and preventing the piston from being blown out. The piston-rod is furnished with a shoulder, which serves to support different weights which are placed upon it, and they can be changed at pleasure. The side of the cylinder is pierced with holes opening to the air: the holes are very small, and placed above each other at the distance of about a line; but

this distance, as well as the number of them, is a matter of indifference.

To give an idea of the effect of this small apparatus, let us suppose the piston lowered, and loaded with any weight, and that a fire is kindled under the boiler. When the vapour has acquired sufficient elasticity to raise the weights, the piston will ascend; and having passed the first hole, some vapour will escape.

If this aperture be of sufficient size for the passage of the quantity of vapour continually produced, the piston will remain there stationary, and in a state of oscillation; if not, it will ascend above the second, third, &c. hole; and if the intensity of the fire is sufficiently strong, above the last, which must be made larger, that, by giving the proper means of escape to the vapour, all accidents may be prevented. It is here evident, that though the greater or less elevation of the piston, as well as the number of the holes open, depend on the variations and different intensities of the fire, these variations, however, have no influence on the interior heat, and the elasticity of the vapour contained in the digester, since their force is always proportioned to the weight with which the piston is loaded, and which is constant. This safety-piston seems likely to afford, for delicate experiments, greater exactness than the usual safety-valves hitherto employed, with levers charged with weights: for in the whole course of the space which the cylindric piston passes over in ascending, the state of the elasticity of the vapour is the same; whereas, when the conical valve in common use is once raised up, nothing indicates whether or how much the present state of the vapour surpasses the first effort it made to open the valve. Besides, the diameter of the piston being once known, the force of the vapour requisite for each experiment can be easily regulated and determined: if we suppose, for example, that the lower surface of the piston is $\frac{1}{4}$ th of a square inch, each ounce of weight placed on the shoulder of the piston-rod will be equivalent to the pressure of a pound on each square inch of the surface, and so on in proportion. As this pressure then remains constant, the experiment will be more determinate, and consequently more comparative. The application of this piston to the boiler of the steam-engine needs no farther explanation, except that, in this case, the diameter of the piston must be considerably increased. It seems here to offer the same advantage of greater uniformity in the force of the steam, especially if the motion of the piston be employed to regulate the fire of the furnace, and to prevent the useless dispersion of the vapour, by preventing an excess in the intensity of the fire. The following apparatus may be used for this purpose. Let the aperture of the flue for the current of air which maintains the combustion of the fuel be provided with a register, which, by rising and falling, will open or shut that passage of air: if the motion of the safety-piston be combined by any means with the register, in such a manner that when the former ascends, the latter descends, so that when the piston is at its greatest elevation, the register shall be entirely shut, it is evident that since the heat produced depends on the access of the air, the elasticity of the vapour, being determined by the weight on the piston, will not only remain within the bounds prescribed for it, but will regulate itself, by preventing any more air from entering the furnace than is necessary to maintain its force. A figure, representing this useful apparatus more minutely, may be found in the 17th volume of the Philosophical Magazine, p. 162.

Before quitting the subject of double-cylinder engines,

we shall notice some others beside those of Mr. Hornblower and Mr. Woolf.

Messrs. James and John Robertson had a patent for one in 1800. The professed object of the double cylinder was to save that portion of steam, which in the best constructed steam-engines escapes past the sides of the piston in the time of working, and is lost without producing any mechanical effect whatever. Mr. Robertson's intention was to prevent so great a quantity of steam from escaping, and in making the steam, which actually did escape, act on another piston, and add to the power of the engine. There are two steam-cylinders, with a piston fitted to each; the one cylinder of a smaller, and the other of a larger size. These two cylinders act together in producing the effect, and are furnished with a condensing vessel and air-pump, similar to other engines. The same patent contains the description of the smoke-burning furnace, which has been very extensively used.

Mr. William Deverell obtained a patent in 1805, for improvements in the steam-engine. He proposes to have two working cylinders, placed near to one another, each having a pipe of communication, with a large vessel, in which the steam, after passing from the small cylinder, is suffered to expand itself, before entering the large cylinder. The pistons in the two cylinders work alternately up and down by means of valves or cocks, opening and shutting as in the common engine. Suppose the small piston has just made a stroke, and a passage is opened to the steam-vessel at the end of the stroke; at first beginning to work the engine, the vessel will be full of steam of about 18lbs. pressure, admitted from the boiler, but afterwards will only be supplied by the steam thrown into it from the small cylinder. The vessel should be about twenty times larger in capacity than the smallest working cylinder; and the larger it is, the more regular will be the pressure on the great piston, which is worked by the steam coming from the steam-vessel. If the steam in the boiler be of 54lbs. pressure *per* square inch, the ratio of the two working cylinders may be as 1 to 3, for then the smaller one will supply the larger with steam of about 18lbs. pressure: the proportion, however, may be varied, though these are thought best by the patentee. The improvements here are represented to consist in the steam going from the smaller working cylinder to the steam-vessel, and then from the steam-vessel to the larger working cylinder, from which it is afterwards drawn off, and condensed. By these means the engine will be very regular in its operations. Suppose the steam in the boiler is at 54lbs., the smaller cylinder will, at the end of the stroke, be full of steam of the same or nearly the same force; and the steam-vessel being full of the steam delivered to it by the former stroke of the small cylinder, at about 18lbs. pressure, the communication is opened between this vessel and the smaller cylinder, and the steam in each of these will be brought to nearly 20lbs. pressure, which steam will be used in the great cylinder at the next stroke. But at the end of each stroke of the pistons, before the opening is made between the smaller cylinder and the steam-vessel, the steam in the smaller cylinder will be, as before stated, at about 54lbs.; in the steam-vessel it will be at about 18lbs., and in the larger working cylinder at about 18lbs. also. Hence the medium pressure on the piston of the smaller cylinder will be about 35lbs. on the inch, while the medium pressure of the steam on the piston of the great cylinder will be about 19lbs. on the inch; for it will be about 20lbs. at the beginning, and about 18lbs. at the end of the stroke. If the steam-vessel be made larger, the difference at each end of the stroke will

not be so great. If the steam was let out at 54lbs. from the smaller cylinder to the open air, there would be but 39lbs. upon each inch of the piston, in consequence of the re-action of the atmosphere, equivalent to about 15lbs. per inch: thus, by letting the steam pass from the smaller cylinder to the steam-vessel, instead of letting it out to the open air, it loses about 4lbs. on the inch of the small piston, but it gains about 12lbs. on the inch of a piston three times as large; and there being but half the steam required in the common way to condense, there must of necessity be a considerable gain. If the friction and loss of force be equal to 9lbs. on the inch on the piston of the smaller cylinder, there will be but about 30lbs. on the inch neat power, when the larger one will work about 12lbs. on the inch. Here too, if the large cylinder, or piston, or air-pump, or condenser, should be out of order, the small piston may still be worked, by disengaging the large piston from the beam: on the other hand, if the smaller piston be out of order, the large one may still be worked, while the other is disengaged. The steam-vessel is to be made of wood, that it may transmit the heat slowly, and the cylinders may be placed within it, if found convenient.

We have examined two engines of Mr. Deverell's which worked with great regularity, but the nature of the work they were performing did not admit of any accurate estimate of their power. The quantity of fuel they consumed was but small. We are disposed to think the addition of the steam-vessel for the steam to expand itself in, is advantageous in regulating the pressure, provided the heat is kept up; and for this purpose, the steam-vessel in one of the engines we speak of was inclosed in the boiler, and we think would, in that case, receive a constant addition of heat to the expanded steam within it, which we believe is essential to all these kinds of engines. See the specification at large in the Repertory of Arts, vol. viii. p. 81.

Messrs. Fox and Lean have also a patent, dated Dec. 10, 1802, for improvements on steam-engines, the principal part of which is a double-cylinder engine, very much resembling those which we have described. See the Repertory, vol. xxiii. p. 200.

Application of Reciprocating Engines to produce a rotative Motion for turning Machinery.—We have hitherto considered the steam-engine as being confined to the operation of working pumps for raising water; except in the slight notice which we have taken of the application of the crank to the atmospheric engine. This was a thing so obviously in imitation of the foot-lathe, as to be scarcely considered an invention; but the difficulty of applying it to use arose from the want of regularity in the action of the old engine. An engine to work a crank, must at all times make exactly the same length of stroke; and to perform well, all these strokes must be performed in an equal period of time. The old engines had very little exactness in either of these particulars. From the nature of the detent which opened the injection-cock, and the great friction of turning it, the degree to which it was opened was not constantly the same in the succeeding strokes; and a very small difference of opening would materially influence the quantity of injection, and consequently the vacuum and velocity with which the piston would descend. The boilers also of the old engines were always made too small, so that the least alteration in the intensity of the fire made the engine vary its speed.

At present, in the coal-countries the atmospheric engines are made to work machinery by means of a crank, and perform very well, but they are lightly loaded, and move very quickly. The steam in the boiler is made much stronger

than formerly, to enable it to fill the cylinder with a sudden puff, and thus to displace the air and water in an instant, because the rapid motion of the piston will not allow sufficient time for the discharging to be performed with weak steam, as is usual. All these circumstances reduce the performance of the engine with respect to coals, and the consumption is very great in comparison with the work they perform. Such engines act very well when the work or resistance is constantly the same throughout the day; but the engine cannot work regularly, except when the counter-weight of the connecting rod is equal to half the descending force of the piston, so as to make the stroke upon the crank of equal force in ascending and descending. In breweries, and those works which demand attention to varying resistance, this cannot apply: for instance, when the machinery for grinding is disengaged, or thrown off, if something does not operate to retard the effect of the counter-weight, the engine will increase in its velocity beyond all bounds, so as to work itself to pieces; and as the only remedy is to check the quantity of steam at the returning stroke, the discharge of the air will be interrupted, and the engine must stop. Mr. Watt's single engine accommodates this circumstance, from the mode of discharging being constant, and not possible to be effected by the work applied to it, whether it be uniform or variable: hence, to lessen the momentum of the counter-weight, it is only to check the entrance of the steam by any contrivance that will prevent the valve, which admits steam to enter above the piston, from opening to its greatest limits.

Mr. Watt, for some years after the first introduction of his engines, was so fully occupied in substituting them for the large atmospheric engines at mines, where the expence of fuel was threatening to put a stop to their proceedings, that he found no leisure for new speculations; and although the advantages of applying engines on his principle to actuate machinery had early occurred to him, he did not seriously set about reducing his ideas to practice until the year 1778 or 1779. In the first model he then made, in order to equalize the power, he employed two cylinders, acting upon two cranks fixed upon the same axis, at an angle of 120° from each other, and a weight was placed upon the circumference of the fly-wheel at an angle of 120° from each of the cranks; which weight was to be so adjusted, as to turn the wheel when neither of the cranks could do so, and consequently to render the power nearly equal. This model performed to satisfaction; but Mr. Watt having neglected to take out a patent immediately, the essential part of the contrivance was communicated, as we are informed in the Edinburgh Review, by a workman employed to make a model, to the persons engaged about one of Mr. Washbrough's engines, of which we have before spoken, and a patent was taken out for the application of the crank by the engineer there employed. This did not deter Mr. Watt from proceeding; and without attempting to dispute a patent which, so long as it continued attached to the common atmospheric engine, could not rival him, he set about other modes of effecting the same thing, and took out a patent for several new methods of applying the vibrating or reciprocating motion of steam-engines to produce a continued rotative motion round an axis, one of which was that beautiful contrivance of the revolving motion of one wheel round the other, called the sun and planet wheels, from the resemblance to the motion of those luminaries. Mr. Watt's patent is dated October 1782, and entitled, a new method of applying the vibrating or reciprocating motion of steam-engines to produce a continued rotative or circular motion. It contains six different methods; but the two which have been since brought into use

are the crank, and sun and planet wheels. The crank is applied in the best manner to produce a regular motion, when a single acting engine is the moving power: this was to apply an iron wheel on the end of the axis of the fly-wheel for a crank, and with a pin projecting from it, to which the connecting rod is jointed: one half of the wheel is made solid, of cast-iron, in order to be heavy on that side in which the pin is fixed, so as to urge round the fly during the returning stroke of the engine; the other half of the wheel is made light, that it may not oppose this weight.

Soon after this patent, Mr. Watt erected some engines in London at the large breweries; the first was at Mr. Goodwyn's, a spirited encourager of improvements, and the next at Mr. Whitbread's. A sketch of the latter engine, which is still working, is given in our plate *Porter-Brewery*. In these engines he employed the sun and planet wheels, and used a massive connecting rod, of sufficient weight to actuate the fly during the returning stroke, for these engines had not the advantage of the double action.

Double-acting Steam-Engines.—The advantage of a double-acting engine, which shall urge the machinery equally in ascending and descending, is obvious. The first double-acting steam-engine was proposed in 1779, by Dr. Falck, who published an account and description of an improved steam-engine, which will, he says, with the same quantity of fuel, and in an equal space of time, raise above double the quantity of water raised by any lever-engine of the same dimensions; but he does not appear to have proved the assertion, or constructed even a working model of his proposed engine, which was on Newcomen's principle. The chief improvement which he suggests is to use two cylinders, into which the steam is alternately admitted by a common regulator, which always opens the communication of the steam to one, whilst it shuts up the opening of the other. The piston-rods are kept (by means of a wheel fixed to an arbor) in a continual ascending and descending motion, in the same manner as the rods of the common air-pump, by which they move a common axle; to which is affixed another wheel, moving the pump-rods in the same alternate direction as the piston-rods, by which alternate motions of the two pistons the pumps are kept in constant action. Since the improved engines of Mr. Watt have been introduced, this method of combining the alternate action of two single engines has been applied to work machinery. We have seen both the atmospheric engine and the single engine of Mr. Watt working in this manner, but his double engine is much preferable. Mr. Watt saw that this was necessary, in order to perfect the application of his steam-engine; he therefore applied the power of the steam to press the piston upwards in its cylinder as well as downwards, by forming the vacuum alternately above and below the piston, and the counter-weight then becomes unnecessary. The only change in the machine beside the arrangement of the valves and their mechanism, was in applying a double chain to the arch-head of the beam, in the same way that the pumps of old extinguishing engines were worked; or he employed a rack and sector at the end of the beam.

This he called the *double engine*, as in fact it doubled the power exerted within the same cylinder. He had long had in his mind the idea of this improvement, and had even produced a drawing of it to the house of commons, in 1774, at the time he procured the act to prolong his original patent for 25 years; but the first he executed was, we believe, at Soho, in the year 1781 or 1782, and the first public exhibition of it at the Albion mills a few years later.

About the same period, finding double chains, or racks

and sectors, very inconvenient for communicating the motion of the beam, he invented and applied what has been called the *parallel motion*, one of the most ingenious and most perfect contrivances in mechanics. To prevent irregularities in the speed of the engine, arising from variations in the quantum of power used at different intervals in the works to which it was applied, he made an application of the centrifugal force of what is called the governor (before used in wind-mills), to regulate the admission of the steam; by this means keeping the engine always at an uniform velocity, and diminishing the consumption of steam, in proportion to the power exerted. This gave the finishing stroke to the perfection of the motion of the machine, and rendered its regularity nearly correspondent with that of the pendulum of a clock. These inventions are detailed, among many other contrivances, relative both to steam-engines and the application of their power, in two patents, dated 1782 and 1784. Some of these are highly ingenious; a few may have been first ideas, not reduced to practice, and others were no doubt inserted for the purpose of guarding against evasion.

Messrs. Boulton and Watt's Double-Acting Engine for turning Mills.—Plate VI. contains a general elevation of the whole engine, and Plate VII. *fig. 1.* is a section of the cylinder, inclosed in its steam-case or jacket, the outside of which is coated with plaster, to keep in the heat: the internal structure will be described hereafter: *a* is the piston-rod, connected to the great working beam C B E, by a system of levers *b, c, d, m*, called a parallel motion, the property of which is, that the rectilinear motion of the piston-rod, *a*, is preserved, though the end, C, of the beam describes an arc of a circle when it rises and falls upon its centre of motion, B. At the opposite end, E, of the beam is jointed the connecting rod D, and at the lower end of this is Mr. Watt's contrivance for communicating the force of the steam-engine to any machine of the rotatory kind. G represents the rim and arms of a very large and heavy cast-iron fly-wheel; on the extremity of its axis is fixed the concentric toothed wheel H, called the sun-wheel. The connecting rod, D I, is a strong and stiff iron rod, D, of sufficient weight to balance the piston: to the lower end of it, a toothed wheel, I, is firmly fixed by three bolts, so that it cannot turn round. This wheel is called the planet-wheel, because it revolves round the sun-wheel; it is of the same size and in the same vertical plane with the wheel H, and an iron link or strap (which cannot be seen here, because it is on the other side of the two wheels) connects the centres of the two wheels, so that the one cannot quit the other. The engine being in the position represented in the figure, to explain the action of this movement, suppose the fly, G, to be turned once round by any external force, in the direction from G towards K, it is plain, that since the toothed wheels, being kept together by the link, cannot quit each other, the outer half of the sun-wheel (that is, the half farthest from the cylinder) will work on the inner half of the planet-wheel I, so that at the end of the revolution of the fly, the planet-wheel must have arrived to the top of the sun-wheel H, because the circumferences of the wheels are equal, and the outer end, E, of the beam must be raised to its highest position. The next revolution of the fly will bring the planet-wheel, and the beam connected with it, to their first positions, and thus every two revolutions of the fly will make a complete period of the beam's reciprocating movements. Now, instead of supposing the fly to drive the beam, let the beam drive the fly, the motions must be precisely the same, and each ascent or descent of the piston will produce one revolution of the fly.

For instance, when the piston-rod, *a*, is caused to ascend by the pressure of the steam beneath its piston, it raises one end of the beam and depresses the other; and by the communication of the connecting rod D, causes the planet-wheel I, to turn the wheel H, and the fly-wheel, round with a double velocity. As soon as the piston-rod arrives at the end of its stroke, it receives a new impulse, which brings it down again, and consequently raises the connecting rod D, and planet-wheel I, so as to continue the motion of the wheel H, and fly-wheel G, always in the same direction. The use of the fly-wheel is to acquire an impetus from the force communicated to it, at the time that the centre of the planet-wheel, I, is on the same horizontal line with the centre of the sun-wheel H, at which time the connecting rod exerts all the force of the engine upon the wheel H, to turn it round. This momentum is preserved by the rapid motion of the fly-wheel, which continues to turn all the rest of the machinery, when the planet-wheel, I, is at the top or bottom of its motion, for the centres of the two wheels being in a line with the connecting rod, it has no tendency to turn them round.

To describe the manner in which the power of the steam is given to the piston-rod *a*, we must turn to the section in Plate VII. *fig. 1.* where A is the jacket or steam-case containing the cylinder, which is of cast-iron, and truly bored; it is closed at top by an iron lid *l*, screwed on by screw-bolts, passing through a projecting rim or flanch at the top, and a similar flanch is formed at the lower end of the cylinder, to fall on the bottom. In the centre of the top lid is a stuffing-box, *l*, for holding a packing of hemp, through which the piston-rod, *a*, passes, perfectly air and steam tight: 20 is the piston, packed with hemp in a channel round its edge, so that the packing lies between its circumference and the inside surface of the cylinder; and while it can move up and down in the cylinder easily, it will not allow any steam to pass by it. The piston is fitted to the rod, *a*, with a cone, and fast keyed in: the cylinder has a flanch or projecting ring round it, a little below the top flanch, by which it is held into the jacket A, which is constantly supplied with steam from the boiler of the engine, by a small pipe branching off from the steam-pipe.

The steam-pipe cannot be seen in the elevation, except by the small dark circle near *g*; and in *fig. 2.* it is marked 21: it introduces the steam from the boiler, at all times, through a throttle-valve, 25, into a box *g*, called the upper steam-box. In the bottom of this box is the upper steam-valve, which being opened by depressing the end of the lever 7, admits the steam into the short passage 14, which leads to the top of the cylinder. A branch, 12, descends perpendicularly from the steam-pipe, just before it enters the upper steam-box, and conveys steam to the lower steam-box *i*; and in the bottom of this is a valve, which can be opened by lifting the end of a lever, 10, to admit the steam into the passage 15, which leads into the bottom of the cylinder. These two valves govern the entrance of steam into the cylinder; and they both open upwards.

The valves for carrying off the steam are situated in two other boxes, *h* and *k*, in which a vacuum is always maintained by their open communication with the condenser M, by the exhausting-pipe 13, which descends from the upper box *h*, and where it passes by the lower box *k*, has a small branch leading into it.

These two exhausting boxes are situated immediately beneath the passages, 14 and 15, which lead to the top and bottom of the cylinder, and the exhausting-valves are situated in the horizontal plate of the partition between the boxes

and the passages, in the same manner as the steam-valves are in the partitions between the steam-boxes and the same passages, as is clearly shewn in *fig. 3.* On opening the upper exhausting-valve, by depressing the lever 8, the steam from the top of the cylinder will be drawn off to the condenser; or by elevating the lever 9 (*fig. 2.*), the lower exhausting-valve will be opened, and the steam will pass off from the lower part of the cylinder to the condenser.

The steam and eduction-valves, 7, 8, 9, 10, are opened and shut by the levers called spanners, whose handles, 1 and 2, are alternately moved by the plugs fixed to the piston-rod of the air-pump N. This part of the machinery has been called the hand-gear, because it is so constructed that the steam and eduction-valves can be worked either by the hand or by the piston of the air-pump.

The valves are connected in pairs to levers upon the axle of the two handles 1 and 2, which are actuated by the pins *f* and 24, projecting from the rod, *f*, of the air-pump, and the arrangement is this; the lower steam-valve 10, and the upper exhausting-valve 8, are connected by rods with levers upon the axle of the lower handle 2, and when that handle is depressed it will open both those valves at once, to admit steam below the piston, and exhaust it from above, which will cause the ascent of the piston. A lever and rod 6, (see the elevation) are applied to the axis of this handle, with a sufficient weight in the cistern to cause the handle to fall and open the valves suddenly; but when the valves are to be kept shut, the handle, 2, is held up by a catch, and detent 3 4, the end, 4, having a hook to receive the catch, and detain the handle when lifted up, as in the figure.

In the same manner, the upper steam-valve 7, and the lower exhausting-valve 9, are united by rods to levers fixed upon the axis of the upper handle 1; and when this handle is raised, as in the figure, it opens both valves at once, so as to admit the steam above the piston and exhaust it from beneath it, as is shewn by the arrows in the section, which will cause the piston to descend.

Like the former spindle, a lever, 5, and rod are applied to it, with a weight which will lift up the handle, 1, and open the two valves; but when the handle is depressed, so as to shut the valves, it is held down by the catch entering the hook, 3, of the detent 3 4. As this detent moves upon a centre-pin, it must be observed, that when one lever catches into the hook it pushes back the detent, and this motion releases the other catch from the hook at the opposite end of the detent, so that moving one handle to shut one pair of valves releases the catch, and the weights immediately open the opposite pair of valves.

The exhausting-pipe, 13, descends to the condenser M, which is a cylindrical vessel of cast-iron, immersed in the cold water of the condensing cistern L; it communicates by the valve *m*, with the air pump N, which has valves in its bucket opening upwards, and is covered by a lid, through which the rod passes in a stuffing-box; also at the top of the pump is a short pipe of discharge, opening into the hot-well *n*, and this has a valve to prevent the return of the air and water into the pump.

All these parts are exactly the same as those of the single engine, before described, except the injection-cock 16, which is constantly running a small jet of cold water into the condenser, when the engine is at work. There is no necessity for an injection-valve in the double engine, and the use of the cock is only to regulate the quantity, and to stop it when the engine is not at work: it is moved by a handle 17, and there is a divided plate and index, to shew the degree of opening.

The cylinder is bolted down to two strong beams, which cross over the top of the condensing cistern *L*, and these are united at the ends to two vertical posts *S*, which are framed into another piece situated beneath the cistern, and supported upon a pier of brick-work *R*: by this means the whole weight of the water in the cistern is applied to hold the cylinder firmly down. *K* are beams which support the strain of the beam-centre, by bearing up the floor *F*, on which the centre bearing rests; and the narrow dark line up the middle of the frame *K*, is a large iron bolt, which ties the frame down to the long groundfills, on which the cistern rests, and with which the beam *T*, for the centre of the fly-wheel, is connected by oblique legs and tie-bolts: by this means the external walls, *W, W*, are relieved from any material strain occasioned by the working of the engine. *XX* is the staircase to ascend to the beam-floor. The boiler is not represented, but may be considered the same as that of the single engine.

Operation of the Double Engine.—Supposing every thing in the position of the section, the operation of the engine is as follows. When the water in the boiler is heated by the fire made under its bottom, the heat which enters into combination with the water causes it to expand, and form steam: in this state it rises and fills the boiler, and thence passing through the pipes *21*, enters the upper steam-box *g*; it also enters between the jacket, and warms the cylinder; and by the descending branch, *12*, of the steam-pipe, enters and fills the lower steam-box *i*. Before the engine can be worked, the steam must be heated, until it is expanded so much, that it will rush forcibly out of the boiler when permitted.

The person who attends the engine must now open all the four valves at once, by elevating the handle *1*, and depressing the handle *2*; this admits the steam from the boiler to pass through the boxes and the cylinder to the condenser, when it rushes through the pipe, *13*, into the condenser *M*, driving the air therein contained through the valve *m*, and the valves in the bucket of the air-pump, which it opens, and passes into the cistern *n*, through the discharge-valve, where it is open to the atmosphere, the lid of that cistern being only laid on, and not fitting tight. This operation (called blowing through) being continued for a few seconds, expels all the air from the condenser, and fills it with hot steam. All the four valves are now closed, by pressing down the upper handle *1*, and lifting up the lower handle *2*; and the injection-cock *16*, of which *17* is the handle, is opened: this allows a small stream of cold water from the condensing cistern, *L*, to enter into the condenser, and condenses the steam or cools it, when it instantly contracts into the same space it originally occupied in the boiler, before it was heated. As the valve, *m*, closes, to prevent the return of the atmospheric air, a vacuum will be caused in the condenser, because there will be nothing in it but that small quantity of water produced from the steam, and the cold water injected into the condenser.

The engine-man now opens the upper condensing valve *8*, and lower steam-valve *10*, by allowing the lower handle, *2*, to fall down. The communication to the condenser being thus opened, the mixture of air and steam in the upper part of the cylinder will expand itself into the condenser through the passage *14*, and valve *8*, by the exhausting-pipe *13*: as it occupies more space than it did before, it will be considerably rarefied, and press lightly upon the upper side of the piston. The steam from the boiler entering through the open valve, *10*, is all the while pressing with its full force against the lower side of the piston, and will perhaps, now

a rarefaction is made above it, overcome the resistance of the work and friction, and cause the piston to ascend, the air-pump rod and bucket moving with it. When the pin *24*, upon this rod, reaches the handle *2*, it raises it up, and shuts the lower steam-valve *10*, and the upper exhausting-valve *8*; and by means of the catch pressing back the hook at the lower end of the detent *4*, it relieves the catch of the upper handle from the hook, *3*, of the detent; in consequence of which, the weight applied to the lever *5*, throws up the handle *1*, and opens the upper steam-valve *7*, and lower exhausting-valve *9*, while the hook, *4*, of the detent, receiving the catch of the lower handle *2*, holds it up. This is the situation represented in the section in *fig. 1*. The operation is now reversed; the steam from the boiler going through the valve *7*, and passage *14*, into the cylinder above the piston, as shewn by the arrows, *fig. 1*; and that steam which is beneath the piston going through the passage *15*, and valve *9*, to the condenser, where the steam will be condensed, and a vacuum will be formed beneath the piston: the steam now presses it down, moving the beam, and turning the fly-wheel and other machinery which it has to drive. When the piston is at the bottom, the pin, *f*, on the air-pump rod arrives at the handle *1*, and presses it down; this shuts the upper steam-valve *7*, and lower exhausting-valve *9*; and when they are completely shut, the catch of the upper handle, in entering the upper hook of the detent *3*, disengages the lower hook thereof; and the weight *6*, which is applied to the lower handle *2*, immediately throws open the lower steam-valve *10*, and the upper exhausting-valve *8*: the steam entering at the lower passage *15*, the piston will be driven up again.

At each stroke of the engine, when the piston rises, the valve in the bucket of the air-pump will shut, and all the air and water contained above the bucket will be lifted through the valve, *n*, into the cistern or hot-well; at the same time, a vacuum being made beneath the bucket, which is more perfect than that in the condenser, the valve, *m*, will be opened by the water and air in the condenser, which will enter the pump. On the descent of the piston, and air-pump bucket, the valve *m*, and the discharging-valve, *n*, will be shut, because the pressure which opened them is removed; and the water and air in the pump pressing upon the valves in the bucket will open them, and pass through the bucket as it descends. At its return, it raises and discharges the water and air above it at the valve *n*, as before.

In this manner, when the engine has made two strokes, all the air which was contained in the cylinder, and mixed with the steam at the commencement of the operation, which was the only part from which it could not be expelled by blowing through, will be pumped out. The operation of the engine is now more perfect; the instant the exhausting-valve is opened, so as to establish a communication from the cylinder full of steam to the condenser, the elasticity of the steam causes it to rush through the valve, down the pipe *13*, into the condenser: when it arrives there, it meets the stream of the injection-water, which condenses it, the remaining steam in the cylinder following it surprisingly quick; and in an instant, an almost perfect vacuum is formed in the cylinder, so that the steam acts with its whole force upon the piston to give it motion, all resistance upon the other side being removed.

The air-pump has now only to draw off from the condenser the water injected into it, the water produced by the condensed steam, and that small quantity of air or gas which goes from the boiler with the steam, and will not be condensed by the cold water. These are delivered

For instance, when the piston-rod, *a*, is caused to ascend by the pressure of the steam beneath its piston, it raises one end of the beam and depresses the other; and by the communication of the connecting rod *D*, causes the planet-wheel *I*, to turn the wheel *H*, and the fly-wheel, round with a double velocity. As soon as the piston-rod arrives at the end of its stroke, it receives a new impulse, which brings it down again, and consequently raises the connecting rod *D*, and planet-wheel *I*, so as to continue the motion of the wheel *H*, and fly-wheel *G*, always in the same direction. The use of the fly-wheel is to acquire an impetus from the force communicated to it, at the time that the centre of the planet-wheel, *I*, is on the same horizontal line with the centre of the sun-wheel *H*, at which time the connecting rod exerts all the force of the engine upon the wheel *H*, to turn it round. This momentum is preserved by the rapid motion of the fly-wheel, which continues to turn all the rest of the machinery, when the planet-wheel, *I*, is at the top or bottom of its motion, for the centres of the two wheels being in a line with the connecting rod, it has no tendency to turn them round.

To describe the manner in which the power of the steam is given to the piston-rod *a*, we must turn to the section in *Plate VII. fig. 1.* where *A* is the jacket or steam-case containing the cylinder, which is of cast-iron, and truly bored; it is closed at top by an iron lid *l*, screwed on by screw-bolts, passing through a projecting rim or flanch at the top, and a similar flanch is formed at the lower end of the cylinder, to fall on the bottom. In the centre of the top lid is a stuffing-box, *l*, for holding a packing of hemp, through which the piston-rod, *a a*, passes, perfectly air and steam tight: *20* is the piston, packed with hemp in a channel round its edge, so that the packing lies between its circumference and the inside surface of the cylinder; and while it can move up and down in the cylinder easily, it will not allow any steam to pass by it. The piston is fitted to the rod, *a*, with a cone, and fast keyed in: the cylinder has a flanch or projecting ring round it, a little below the top flanch, by which it is held into the jacket *A*, which is constantly supplied with steam from the boiler of the engine, by a small pipe branching off from the steam-pipe.

The steam-pipe cannot be seen in the elevation, except by the small dark circle near *g*; and in *fig. 2.* it is marked *21*: it introduces the steam from the boiler, at all times, through a throttle-valve, *25*, into a box *g*, called the upper steam-box. In the bottom of this box is the upper steam-valve, which being opened by depressing the end of the lever *7*, admits the steam into the short passage *14*, which leads to the top of the cylinder. A branch, *12*, descends perpendicularly from the steam-pipe, just before it enters the upper steam-box, and conveys steam to the lower steam-box *i*; and in the bottom of this is a valve, which can be opened by lifting the end of a lever, *10*, to admit the steam into the passage *15*, which leads into the bottom of the cylinder. These two valves govern the entrance of steam into the cylinder; and they both open upwards.

The valves for carrying off the steam are situated in two other boxes, *b* and *k*, in which a vacuum is always maintained by their open communication with the condenser *M*, by the exhausting-pipe *13*, which descends from the upper box *b*, and where it passes by the lower box *k*, has a small branch leading into it.

These two exhausting boxes are situated immediately beneath the passages, *14* and *15*, which lead to the top and bottom of the cylinder, and the exhausting-valves are situated in the horizontal plate of the partition between the boxes

and the passages, in the same manner as the steam-valves are in the partitions between the steam-boxes and the same passages, as is clearly shewn in *fig. 3.* On opening the upper exhausting-valve, by depressing the lever *8*, the steam from the top of the cylinder will be drawn off to the condenser; or by elevating the lever *9* (*fig. 2.*), the lower exhausting-valve will be opened, and the steam will pass off from the lower part of the cylinder to the condenser.

The steam and eduction-valves, *7, 8, 9, 10*, are opened and shut by the levers called spanners, whose handles, *1* and *2*, are alternately moved by the plugs fixed to the piston-rod of the air-pump *N*. This part of the machinery has been called the hand-gear, because it is so constructed that the steam and eduction-valves can be worked either by the hand or by the piston of the air-pump.

The valves are connected in pairs to levers upon the axle of the two handles *1* and *2*, which are actuated by the pins *f* and *24*, projecting from the rod, *f*, of the air-pump, and the arrangement is this; the lower steam-valve *10*, and the upper exhausting-valve *8*, are connected by rods with levers upon the axle of the lower handle *2*, and when that handle is depressed it will open both those valves at once, to admit steam below the piston, and exhaust it from above, which will cause the ascent of the piston. A lever and rod *6*, (see the elevation) are applied to the axis of this handle, with a sufficient weight in the cistern to cause the handle to fall and open the valves suddenly; but when the valves are to be kept shut, the handle, *2*, is held up by a catch, and detent *3 4*, the end, *4*, having a hook to receive the catch, and detain the handle when lifted up, as in the figure.

In the same manner, the upper steam-valve *7*, and the lower exhausting-valve *9*, are united by rods to levers fixed upon the axis of the upper handle *1*; and when this handle is raised, as in the figure, it opens both valves at once, so as to admit the steam above the piston and exhaust it from beneath it, as is shewn by the arrows in the section, which will cause the piston to descend.

Like the former spindle, a lever, *5*, and rod are applied to it, with a weight which will lift up the handle, *1*, and open the two valves; but when the handle is depressed, so as to shut the valves, it is held down by the catch entering the hook, *3*, of the detent *3 4*. As this detent moves upon a centre-pin, it must be observed, that when one lever catches into the hook it pushes back the detent, and this motion releases the other catch from the hook at the opposite end of the detent, so that moving one handle to shut one pair of valves releases the catch, and the weights immediately open the opposite pair of valves.

The exhausting-pipe, *13*, descends to the condenser *M*, which is a cylindrical vessel of cast-iron, immersed in the cold water of the condensing cistern *L*; it communicates by the valve *m*, with the air pump *N*, which has valves in its bucket opening upwards, and is covered by a lid, through which the rod passes in a stuffing-box; also at the top of the pump is a short pipe of discharge, opening into the hot-well *n*, and this has a valve to prevent the return of the air and water into the pump.

All these parts are exactly the same as those of the single engine, before described, except the injection-cock *16*, which is constantly running a small jet of cold water into the condenser, when the engine is at work. There is no necessity for an injection-valve in the double engine, and the use of the cock is only to regulate the quantity, and to stop it when the engine is not at work: it is moved by a handle *17*, and there is a divided plate and index, to shew the degree of opening.

The cylinder is bolted down to two strong beams, which cross over the top of the condensing cistern *L*, and these are united at the ends to two vertical posts *S*, which are framed into another piece situated beneath the cistern, and supported upon a pier of brick-work *R*: by this means the whole weight of the water in the cistern is applied to hold the cylinder firmly down. *K* are beams which support the strain of the beam-centre, by bearing up the floor *F*, on which the centre bearing rests; and the narrow dark line up the middle of the frame *K*, is a large iron bolt, which ties the frame down to the long groundfills, on which the cistern rests, and with which the beam *T*, for the centre of the fly-wheel, is connected by oblique legs and tie-bolts: by this means the external walls, *W*, *W*, are relieved from any material strain occasioned by the working of the engine. *XX* is the staircase to ascend to the beam-floor. The boiler is not represented, but may be considered the same as that of the single engine.

Operation of the Double Engine.—Supposing every thing in the position of the section, the operation of the engine is as follows. When the water in the boiler is heated by the fire made under its bottom, the heat which enters into combination with the water causes it to expand, and form steam: in this state it rises and fills the boiler, and thence passing through the pipes *21*, enters the upper steam-box *g*; it also enters between the jacket, and warms the cylinder; and by the descending branch, *12*, of the steam-pipe, enters and fills the lower steam-box *i*. Before the engine can be worked, the steam must be heated, until it is expanded so much, that it will rush forcibly out of the boiler when permitted.

The person who attends the engine must now open all the four valves at once, by elevating the handle *1*, and depressing the handle *2*; this admits the steam from the boiler to pass through the boxes and the cylinder to the condenser, when it rushes through the pipe, *13*, into the condenser *M*, driving the air therein contained through the valve *m*, and the valves in the bucket of the air-pump, which it opens, and passes into the cistern *n*, through the discharge-valve, where it is open to the atmosphere, the lid of that cistern being only laid on, and not fitting tight. This operation (called blowing through) being continued for a few seconds, expels all the air from the condenser, and fills it with hot steam. All the four valves are now closed, by pressing down the upper handle *1*, and lifting up the lower handle *2*; and the injection-cock *16*, of which *17* is the handle, is opened: this allows a small stream of cold water from the condensing cistern, *L*, to enter into the condenser, and condenses the steam or cools it, when it instantly contracts into the same space it originally occupied in the boiler, before it was heated. As the valve, *m*, closes, to prevent the return of the atmospheric air, a vacuum will be caused in the condenser, because there will be nothing in it but that small quantity of water produced from the steam, and the cold water injected into the condenser.

The engine-man now opens the upper condensing valve *8*, and lower steam-valve *10*, by allowing the lower handle, *2*, to fall down. The communication to the condenser being thus opened, the mixture of air and steam in the upper part of the cylinder will expand itself into the condenser through the passage *14*, and valve *8*, by the exhausting-pipe *13*: as it occupies more space than it did before, it will be considerably rarefied, and press lightly upon the upper side of the piston. The steam from the boiler entering through the open valve, *10*, is all the while pressing with its full force against the lower side of the piston, and will perhaps, now

a rarefaction is made above it, overcome the resistance of the work and friction, and cause the piston to ascend, the air-pump rod and bucket moving with it. When the pin *24*, upon this rod, reaches the handle *2*, it raises it up, and shuts the lower steam-valve *10*, and the upper exhausting-valve *8*; and by means of the catch pressing back the hook at the lower end of the detent *4*, it relieves the catch of the upper handle from the hook, *3*, of the detent; in consequence of which, the weight applied to the lever *5*, throws up the handle *1*, and opens the upper steam-valve *7*, and lower exhausting-valve *9*, while the hook, *4*, of the detent, receiving the catch of the lower handle *2*, holds it up. This is the situation represented in the section in *fig. 1*. The operation is now reversed; the steam from the boiler going through the valve *7*, and passage *14*, into the cylinder above the piston, as shewn by the arrows, *fig. 1*; and that steam which is beneath the piston going through the passage *15*, and valve *9*, to the condenser, where the steam will be condensed, and a vacuum will be formed beneath the piston: the steam now presses it down, moving the beam, and turning the fly-wheel and other machinery which it has to drive. When the piston is at the bottom, the pin, *f*, on the air-pump rod arrives at the handle *1*, and presses it down; this shuts the upper steam-valve *7*, and lower exhausting-valve *9*; and when they are completely shut, the catch of the upper handle, in entering the upper hook of the detent *3*, disengages the lower hook thereof; and the weight *6*, which is applied to the lower handle *2*, immediately throws open the lower steam-valve *10*, and the upper exhausting-valve *8*: the steam entering at the lower passage *15*, the piston will be driven up again.

At each stroke of the engine, when the piston rises, the valve in the bucket of the air-pump will shut, and all the air and water contained above the bucket will be lifted through the valve, *n*, into the cistern or hot-well; at the same time, a vacuum being made beneath the bucket, which is more perfect than that in the condenser, the valve, *m*, will be opened by the water and air in the condenser, which will enter the pump. On the descent of the piston, and air-pump bucket, the valve *m*, and the discharging-valve, *n*, will be shut, because the pressure which opened them is removed; and the water and air in the pump pressing upon the valves in the bucket will open them, and pass through the bucket as it descends. At its return, it raises and discharges the water and air above it at the valve *n*, as before.

In this manner, when the engine has made two strokes, all the air which was contained in the cylinder, and mixed with the steam at the commencement of the operation, which was the only part from which it could not be expelled by blowing through, will be pumped out. The operation of the engine is now more perfect; the instant the exhausting-valve is opened, so as to establish a communication from the cylinder full of steam to the condenser, the elasticity of the steam causes it to rush through the valve, down the pipe *13*, into the condenser: when it arrives there, it meets the stream of the injection-water, which condenses it, the remaining steam in the cylinder following it surprisingly quick; and in an instant, an almost perfect vacuum is formed in the cylinder, so that the steam acts with its whole force upon the piston to give it motion, all resistance upon the other side being removed.

The air-pump has now only to draw off from the condenser the water injected into it, the water produced by the condensed steam, and that small quantity of air or gas which goes from the boiler with the steam, and will not be condensed by the cold water. These are delivered

by the air-pump into the hot-well, *n*, from which the air escapes; and the water, which still continues hot, runs off, when at a certain level, by a waste-pipe, which is not represented.

The water which is boiled off in steam from the boiler, is renewed from the hot-well by means of a small pump, *p*, in the elevation, which draws the water from it by a pipe *o*, conducted up the side of the great frame *K*, which stands at the end of the condensing cistern *L*, and supports the bearing for the centre of the great beam. The water is conveyed from the pump by a pipe, to a cistern placed at the top of a vertical pipe, which descends into the boiler. The top of this pipe is closed by a valve in the cistern, which valve is raised by means of a lever, and the other end has a wire hooked to it, going through a small stuffing-box into the boiler, where a stone is hung to it. This stone is balanced by a weight suspended at the other end of the lever, so that when the stone is covered with water, the weight keeps the valve shut, and prevents any water getting down into the boiler; but as the water sinks in the boiler by the evaporation, the weight of the stone overcomes the weight, and opens the valve: the water in the cistern then runs down the pipe into the boiler, and raises the water therein, and the balance-weight lifts up the stone, so as to close the valve.

The condenser being constantly supplied with hot steam, which gives out its heat, it would at length render the water surrounding it in the cistern so hot, that it would condense no more. To prevent this, it is constantly supplied with cold water from a pump *O*, worked by a rod *P*, from the great beam. The water from the condensing cistern runs off by a waste-pipe at the back of the cistern, but not seen in the figures. The safety-valve is contained in a short pipe fixed upon the boiler, with a lid and a stuffing-box, through which a rod passes to open the valve within, and discharge the steam when the engine is not to be worked any longer. When at work, the valve is pressed down by a lever and weight. If at any time, when the engine is not at work, the steam should be heated, so as to be in any danger of bursting the boiler, the valve will lift up the weight, and allow the steam to escape through the pipe which opens into the chimney.

Other Particulars of the Double Engine. — Mr. Watt's mode of regulating the engine is a most beautiful contrivance, and so perfect, as to put the steam-engine on an equality with a water-wheel, in the regularity of its motion, even when the resistance is very variable. The throttle-valve, which regulates the supply of steam, is placed in the steam-pipe at 25 (*Plate VII. fig. 2.*): it is a thin circular vane in the pipe, turning on a pivot across its centre, which comes through the pipe, and has a small handle fixed on the end of it: by turning this handle, the spindle and vane within the pipe are turned also. When the vane is set, so that its plane is perpendicular to the axis of the pipe, it nearly fills the circular passage, and allows very little steam, if any, to pass by it; but when the vane is turned edgewise, it presents a very small surface, and the steam passes by without obstruction to the steam-boxes *g* and *i*. By turning the handle of the throttle-valve, the engine-man can at any time regulate the speed of the engine, the friction of the axis being sufficient to retain it as it is placed.

This method of regulation is sufficient for many engines; but when the steam-engine is employed to drive machinery, in which the resistance is very variable, and where a determinate velocity cannot properly be dispensed with, Mr. Watt has applied the conical pendulum, which is represented in the elevation (*Plate VI.*) at *b s*, for procuring uniform

velocity. (See also *REGULATOR and MILL-WORK*) This regulator has two pendulums, consisting of heavy balls, *b*, *s*, suspended by iron rods, which move on a common joint, *w*, at the top of the vertical axis *t x*, which is put in motion by an endless rope, *q*, passing round a pulley on the axis of the fly-wheel, and round another pulley upon a small horizontal axis, from which, by means of a pair of bevelled wheels, *r*, the motion is communicated to the vertical axis *t x*, which is caused to revolve, and carry the pendulum with it. In this motion, their balls, *b* and *s*, describe a horizontal circle, and the velocity is sufficient to make the balls fly out by their centrifugal force, the arms of the pendulums moving upon their centres: in this motion, the upper ends of the arms *w*, *w*, draw down a collar, *x*, which slides on the square part of the axis, and operates on a lever *x*, and by another lever *y*, and rod *z*, communicates with the steam or throttle-valve. The action of this beautiful contrivance is this: as the velocity of the fly-wheel increases and diminishes with the quantity of steam that is admitted into the cylinder, let us suppose that too much is admitted; then the velocity of the fly-wheel is increased, and the velocity of the vertical axis, *t x*, will also increase, and the balls *b*, *s*, will recede from the axis by the augmentation of their centrifugal force. By this recede of the balls, the extremity, *x*, of the lever is depressed, its other extremity rises, and acting upon the lever *y*, causes the vane of the throttle-valve to present more surface, to close the passage a little, and diminish the supply of steam. The impelling power of the engine being thus diminished, the velocity of the fly-wheel and the flying balls decreases in proportion, and the balls resume their former position, and the engine works regularly.

The advantage of the sun and planet wheels has been stated to consist in making the fly-wheel revolve with a double velocity to that which would be produced by a simple crank, by which means a fly-wheel of smaller dimensions becomes sufficient to regulate the motion of the engine. Of late years, this ingenious contrivance has been laid aside in favour of the simple crank, because it has been found that the cogs of the two wheels, when they become worn and loose, act with a disagreeable jerk at every change of the motion from the ascent to the descent. As it is in many cases an advantage to make the fly-wheel revolve with a double or triple velocity, a large cog-wheel is applied upon the axis of the crank, and this turns a pinion of only one-half or one-third of the size, fixed upon the axis of the fly-wheel. Here the same defect of the jerk, by the looseness of the cogs, will be experienced; but the wheels being larger than can be used in the sun and planet wheels, a greater number of cogs are brought into action, and the wear upon each will be less: also, this form of the engine can be included in less room, because the centre of the large fly-wheel may be brought beneath the middle of the beam.

The power of the engine, when transmitted by the crank, is extremely variable throughout the different periods of the stroke: at first beginning, the crank being in a line with the connecting rod, the force of the piston has no action at all to turn the crank; but as the crank begins to make a sensible angle with the connecting rod, the force of the piston begins to operate upon the crank to turn it round, and this with a force increasing with the angle at which the connecting rod acts upon the crank, until they are at right angles to each other; and then the whole force of the piston operates to drive round the crank. To shew the increments and decrements of this varying force, we have made out the following table from a projection of an engine on a large scale.

A Table shewing the force which the connecting rod of a steam-engine has to turn round the crank at different parts of the motion. The parts of the engine are supposed to have the following proportions: length of the stroke, 1.; length of the beam, 2.; length of the crank, .5; length of the connecting rod, 3.

Decimal Portions of the Descent of the Piston, the whole Descent being 1.	Angle between the Connecting Rod and Crank.	Effective Length of the Lever upon which the Connecting Rod acts, the whole Crank being 1.	Decimal Portion Half a Revolution of the Fly-Wheel.
	Degrees.		
.0	180	.0	.0
.05	151 $\frac{1}{2}$	.46	.128
.10	141	.62	.158
.15	131 $\frac{1}{2}$	.74	.228
.2	123 $\frac{1}{2}$	.830	.271
.25	117 $\frac{1}{4}$	.892	.308
.3	110 $\frac{1}{2}$	.94	.342
.35	104	.976	.377
.4	97 $\frac{1}{2}$	.986	.41
.45	91 $\frac{1}{4}$	1.	.441
.5	85 $\frac{1}{2}$	1.	.473
.55	80	.986	.507
.6	75	.956	.538
.65	69	.92	.572
.7	62 $\frac{1}{2}$	.88	.607
.75	57 $\frac{1}{4}$	.824	.642
.8	49	.746	.68
.85	42	.66	.723
.9	34	.546	.776
.95	23 $\frac{1}{2}$	.390	.84
1.0	0	.0	1.

The third column of this table also shews the force which is communicated to the fly-wheel, expressed in decimals, the force of the piston being 1.

The above table explains itself by the titles of its different columns, and it is only necessary to remark, that the variations of force are not to be considered as an absolute loss of power, because, when the crank has but slight power, on arriving towards the top or bottom of the stroke, the piston descends proportionably slow; and, in consequence, the steam has more time to flow into the cylinder, and presses upon the piston with a greater power; therefore, what the piston loses in force upon the crank, it makes up in some degree by an increase of its force; and, from moving slower, it consumes less steam than when moving with its whole velocity, and acting with full force upon the crank. Hence both the power and velocity of the piston in the cylinder are to be considered as varying continually; and if the fly is sufficiently heavy, it will be found that the rotative motion is very nearly regular, while the ascent and descent of the piston are accelerated from nothing at the top of the cylinder, to its greatest velocity at the middle, or near the middle, and from that point it is retarded till it comes to nothing at the bottom of the motion. The table shews the exact increments and decrements.

It has been considered desirable to have such a motion, that the power and velocity communicated to the fly-wheel shall be at all times equable and constant. This was one of the first attempts to produce a rotatory motion, as we have mentioned, by Mr. Fitzgerald, at Hartley colliery, in 1768: it has been repeatedly attempted since that period. The most practicable form in which it has been tried was by Mr. Mat-

thew Murray, who, in a patent dated 1799, for the improvement of steam-engines, describes a very ingenious movement for the purpose. The defect of all these contrivances for obtaining equal power on the rotative axis is, that the piston must act upon it all at once with a sudden shock, which in course of time destroys the best constructed mechanism.

In the Philosophical Journal is a description of a contrivance by Mr. Samuel Clegg, for producing a rotative motion from a reciprocating one, which not only simplifies the machine very much, but exceeds the power of the common crank one-third, in consequence of its action being always perpendicular to the radius of the wheel, which is done by a vertical double rack and wheel. The two vertical parts of this rack are joined by a semicircle at the top, and both parts are teathed on the inside, so that the teeth of the vertical wheel are constantly in contact with some of the teeth of the fork formed by the two vertical bars and the semicircle uniting the double racks. The wheel and rack are constantly kept in gear by means of a small roller, a sliding-bar, and a plate, serving, instead of a groove, to keep the roller from deviation in this way. Although the change from the upward to the downward motion of the piston-rod will be gradual, the change from the downward to the upward motion must be instantaneous; or at least the piston-rod must be brought to rest at once, from an uniform motion downwards, and then receive instantaneously a finite velocity in the opposite direction.

A mode of giving a more uniform action to the crank, was attempted in an engine erected by Mr. Hornblower about 1795, at the brewery of Messrs. Meux and Co., where the alternate power of two single cylinders was applied by chains acting upon circular arcs, at a constant distance from the centre of the lever; while the end of the lever which was connected to the crank by the connecting rod continually varied in its action, and consequently in its force on the crank, nearly in an equal proportion to the alteration of the leverage of the crank. (See the sketch of this contrivance at fig. 7. Plate V.) The two cylinders A, B, of this engine made an alternate action on a band-wheel, D, by means of two chains. The lever which carried the connecting rod, F, was a wheel fixed on the same shaft with the band-wheel, and had a pin, E, near its periphery, to which the connecting rod, F, was attached. This pin traversed about 120° of the whole circle, and may be denominated the end of the lever, which, in its action upward to *e*, and downward to *f*, acceded and receded to and from the centre of motion; and had it traversed through the remainder of the semicircle, it would then have pressed on the crank, G, proportionately to the sine of every angle it made in its revolution. But considering the great pressure on this pin in the crank-wheel, it would have demanded a degree of strength in that part which would have been preposterous, compared with the rest of the work.

This engine has its merits and its defects; it is subject to much more friction than a double-acting cylinder, by having two cylinders and their appendages; and unless the communication between the cylinders is clothed with the best materials for that purpose, a great loss of heat must ensue; because the surface exposed in two cylinders, compared with one double-acting cylinder, is as 2 to 1, and the friction of the pistons will be nearly in the same proportion.

The air-pumps in this engine (for it had two, though only one condenser) were worked by a small band-wheel, upon the same axis as the great band-wheel D; and from the opposite sides of this, the rods, *ih*, were suspended by chains. The air-pumps were open at top, and the pressure of the atmosphere always rested upon their pistons; but as the two were acting in opposite directions, they balanced each other as to

power: in this the inventor adopted the common double-barrelled air-pump of Hauksbec, instead of the more perfect air-pump of Smeaton, which Mr. Watt employs. This engine was considered of 36 horses' power, and for many years performed all the work of the brewery. We have also seen some smaller engines built on the same plan, one of them with atmospheric cylinders.

It may be considered as an advantage in this engine, that it has a double air-pump, whereas the double cylinder has only a single air-pump, which draws out the air from the condenser while the piston is making its ascending stroke; but during the descent of the piston the air-pump is inactive. We have seen many proposals for double-acting pumps.

Mr. Murray, in 1801, had a patent for a new air-pump, (see the Specification in the Repertory of Arts, first series, vol. xvi.); but we have not had an opportunity of ascertaining the performance of an engine so constructed; and as the ingenious inventor does not now adopt it in the steam-engines which he makes, we may presume it is not of great importance.

The proportion usually given to the air-pump of a double engine is about two-thirds the diameter of the cylinder, and half the stroke, or from one-fourth to one-fifth the capacity of the cylinder: the condenser is of the same size. Whether it is owing to the circumstance of the single air-pump or not, we are unable to determine; but it appears that double-acting engines do not in general produce so great an effect from the fuel they consume as single engines of the same dimensions. In Messrs. Leans' reports of the engines in Cornwall, which generally contain the accounts of 20 or 25 engines, there are several enormous double engines for pumping the mines, with cylinders of 66 and 65 inches, and four of 63 inches. The best of these appear to be on Williams' mine; cylinder 65 inches diameter, and working with a stroke of 8 feet 9 inches, under a pressure of 16.6 lbs. per square inch: it works 10 pumps, which are a load of 70,411 lbs., at the rate of $6\frac{1}{2}$ strokes per minute, of 6 feet 9 inches each. Its performance with respect to coals was, in June 1816, 30,074,507 lbs. lifted one foot high for each bushel consumed. This is a very good performance; but all the other double engines are less, one of the 63-inch cylinders is 27 millions, the others 25, 22, 21, and even 17 millions.

The advantages are all on the side of the double engine; the diminution of surface which is exposed to condensation, the vis inertie of the parts in motion is much less, and the friction of the piston is very much reduced, although the friction of the joints for communicating the motion must be increased, because they must be bound tight, so as to have no shake or looseness; but this must be inconsiderable.

Before quitting the subject of double engines, employed to give a rotative motion to machinery by a crank, we must notice the remarkable difference, shewn by Messrs. Leans' reports, between the performance of the small engines employed in drawing the matter out of the mines, and those in pumping water.

We should think the loss of power from friction in drawing up buckets by a rope, could not be greater than the friction of pump-buckets, and of the water moving in the pipes; therefore all the difference must be attributed to the application to the rotative motion, and to the smallness of the engines: these are usually 14, 16, and 24 inches in diameter, but their performance, with respect to coals, is only 3, $3\frac{3}{4}$, 4, and 5 millions. The best engine they have draws only from $9\frac{1}{2}$ to 11 million pounds one foot high for each bushel of coals, which is only one-third of the produce of the best large engines employed in pumping.

One of Woolf's double engines at Wheal Fortune mine, in May, 1816, drew only three million pounds one foot high

with each bushel; but another at Wheal Vor mine drew six millions.

Estimation of the Force of Steam-Engines in Horses' Power.

—The method of expressing the mechanical power of any machine by the weight of water or other matter which it will raise to a given height, in a certain period of time, or with a given quantity of fuel, is the most unequivocal expression that can possibly be obtained; but as steam-engines are frequently substituted in the room of horses, it has been customary to calculate their mechanical energy in horse-power, or to find the number of horses which could perform the same work. This, indeed, is a very vague expression of power, on account of the different degrees of strength which different horses possess; but still, when we are told that a steam-engine is equal to sixteen horses, we have a more distinct conception of its power, than when we are informed that it is capable of raising a given number of pounds weight through a certain space in a certain time.

Prior to Mr. Watt's application of the steam-engine to produce rotative motion, the great manufactories of the kingdom had their mill-work put in motion by the agency of water, of wind, or of horses; and the latter had for many years been almost exclusively employed in the breweries and distilleries of the metropolis. It was, therefore, natural for those who wished to substitute the power of steam for that of horses, to state the number of those animals, to which the new power, under given conditions, ought to be equivalent; and it is probable that Messrs. Watt and Boulton felt, that such a mode of comparison would be more intelligible to common apprehensions, than a more accurate and scientific formula: it gave the power of an engine expressed in numbers, of which the ordinary strength of a horse is the unit. This, no doubt, is not in itself very exact, the unit being large, and subject to considerable variation. Relative to the purpose for which it was used, it was, however, sufficiently correct; and on this, as on many similar occasions, a more minute measurement would have been less useful. But to give this unit all the accuracy which can be desired, they have assumed, from the result of experiments made with the strong horses employed by the brewers in London, that the standard of a horse's power is a force able to raise 32,000 lbs. one foot high in a minute: and this, no doubt, was meant to include an allowance of power sufficiently ample to cover the usual variations of the strength of horses, and of other circumstances that might affect the accuracy of the result. In forming the estimate just mentioned, we think the power of a horse is rated above the ordinary average, a circumstance which cannot be complained of by the public, as it tends to represent the advantage of the engines less than it will be found in real practice.

Dr. Brewster, in his edition of Ferguson, states that Messrs. Watt and Boulton suppose a horse capable of raising 32,000 lbs. avoirdupois one foot high in a minute; while Dr. Desaguliers makes it 27,500 lbs. and Mr. Smeaton only 22,916: if we divide, therefore, the number of pounds which any steam-engine can raise one foot high in a minute by these three numbers, each quotient will represent the number of horses to which the engine is equivalent, according to the estimate of these different engineers. We will take, for example, an engine having a double-acting cylinder, on Mr. Watt's plan, 24 inches diameter, and which makes 20 strokes per minute, each stroke being five feet long, and the force of steam being equal to a pressure of 10 lbs. per square inch. Required the number of horse-power of such an engine.

The square of the diameter of the cylinder being multiplied by the decimal number .7854, will give the area of the

piston: thus, $24 \times 24 = 576 \times .7854 = 452.4$ square inches, which are exposed to the pressure of the steam. Now if we multiply this area by 10 lbs., the pressure upon every square inch, we shall have $452.4 \times 10 = 4524$ lbs. the whole pressure upon the piston, or the weight which the engine is capable of raising with a certain velocity. To find this velocity, we say that the engine performs 20 double strokes, each of five feet long, in a minute; the piston must, therefore, move through $20 \times 5 \times 2 = 200$ feet in the same time; and, therefore, the power of the engine will be represented by 4524 lbs. avoirdupois, raised through 200 feet in a minute, or by $9\frac{1}{2}$ hogheads of water, ale measure, raised through the same height in the same time. Now this is equivalent to $4524 \times 200 = 904,800$ lbs. or $9\frac{1}{2} \times 200 = 1848$ hogheads raised through the height of one foot in a minute. This is reduced to the horse-power of Messrs. Boulton and Watt, by dividing by 32,000, their estimate of the horse-power: thus, $904800 \div 32000 = 28\frac{1}{2}$ horses.

According to Smeaton, $904800 \div 22916 = 39\frac{1}{2}$ horses.

According to Defaguliers, $904800 \div 27500 = 33$ horses.

In this calculation, it is supposed that the engine works only eight hours a-day, so that if it worked during the whole 24 hours, it would be equivalent to thrice the number of horses found by the preceding rule.

Other Constructions of Mr. Watt's Double Engine.—A great mass of matter must necessarily be put in rapid motion at every stroke of the reciprocating engine, and the motion must be stopped and returned at the end of the stroke. This is an evident disadvantage under which the double engine labours; for though all objection to the reciprocation, on account of the irregularity of motion, is done away by the application of a fly-wheel, the regularity thus attained is at the expence of the power, as we have shewn in the practical results of the large engines for pumping, and the engines for drawing from the mines. The most obvious improvement in this particular, is to lighten the mass of the great working beam, or to dispense with it altogether. The enormous strain exerted on its arms requires a proportional strength, and this requires a vast mass of matter, not less indeed (in an engine with a cylinder of 52 inches diameter) than three tons and a half, moving with the velocity of three feet in a second, which must be communicated in about half a second, so that this mass must be brought into motion from a state of rest, and must again be brought to rest, again into motion, and again to rest, to complete the period of a stroke. This consumes much power; and engineers have not been able to load an engine with more than 10 or 11 lbs. on the inch of the piston, and preserve a sufficient quantity of motion, so as to make 12 or 15 seven-foot strokes in a minute. Many attempts have been made to lessen this mass, by using a light framed wheel, or a light frame of carpentry, in place of a solid beam.

An example of this is shewn in the beam of Newcomen's engine (*Plate II.*), a method which was introduced by Mr. Smeaton; and another is shewn in Mr. Hornblower's (*Plate V. fig. 1.*) The form of this beam is such, that it would be stronger than a solid beam containing a great many times the quantity of timber, as there is scarcely any part of it which is exposed to a transverse strain, but every piece is either pushed or pulled in the direction of its length. The only evident improvement of which it admits, is to apply a strong tie-bolt along the whole length of the upper beam; because when tie-beams of wood are used, it is very difficult to connect the iron straps to the ends of them in such a manner, that they will not become

loose in time. This is an objection to framed working beams, for although they are abundantly strong at first, yet, after being some time employed, the straps and bolts with which the wooden parts are connected, cut their way into the wood, and the framings become loose in the joints, and, without giving any warning, are liable to break to pieces in an instant. A solid massy simple beam of sufficient strength bends, and sensibly complains, (as the carpenters express it,) before it breaks. In all great engines, therefore, Mr. Watt at first employed such solid beams as were found the most durable, and least likely to break in a long course of work.

They were sometimes strengthened, in a very simple and effective manner, by placing a king-post perpendicular to the length of the beam, over its centre, and extending iron tie-bolts from the top of the king-post to the two extremities of the beam, so that the beam thus framed forms a triangle, of which the beam is the base, the king-post the perpendicular, and the iron ties the sides, meeting the perpendicular at the vertex of the triangle.

This was an expedient generally resorted to, when the beam was found to yield from a long continuance of the action. There is, perhaps, no example, except the mast of a ship, in which a piece of timber is exposed to such a severe strain as the beam of an engine, because it is necessarily made as small as possible; and it is relieved from the strain 15 or 20 times every minute, so that all the fibres are tried to the utmost: we accordingly see old beams, full of cracks lengthwise from the fibres, separating laterally, and after this the beam loses its strength.

Of late years, wooden beams have been altogether disused, and cast-iron beams substituted. We have already described the mode of making the beam for the largest engines, by two plates or flitches put together parallel, and leaving a space between them. For double engines, which are not of the very largest dimensions, it is usual to have the beam cast in one piece, of a form best adapted to give the greatest strength in the least weight. (See *Plate IX. Steam-Engine, Parallel Motions.*) The extremities of the beam are turned in a lathe to form cylindrical pins, and upon these pins are fitted sockets or pieces, which have other pins projecting from them to form the joints of the parallel motion and connecting rod; so that when the sockets are fixed on the ends of the beam, the pins will project from the beam in a direction perpendicular to its length, and parallel to its axis of motion. There are two pins thus projecting from each end of the beam, that is, one pin on each side of the socket: the two links of the parallel motion are fitted to the two projecting pins at one end, and the double joint of the connecting rod is fitted on the two pins at the other end of the beam. The advantage of this construction is, that the joints at the ends of the beam become universal joints, having liberty of motion in all directions: thus, in the direction in which the joints of the parallel motion and connecting rod are required to bend for the motion of the beam, as shewn in the figure, the motion will be upon the projecting pins of the sockets; but if, from the axis of the beam not being rightly placed, or from any other cause, a lateral flexure is required in the motion of the beam, the sockets of the joints will turn a little sideways upon the end of the beam, and allow the deviation, without any strain on the moving parts: were it not for this contrivance, the smallest possible deviation from the perpendicular direction of the cylinder would cause a great friction in the stuffing-box and joints. In Mr. Murray's best engines, the crank-pin is also jointed to the connecting rod by a universal joint. See *Plate VIII. fig. 4.*

All the joints of the parallel motion, the connecting rod,

and crank, in short, all the moving joints of a double engine, must be fitted with brass sockets, which can be tightened round the pivots, so as to prevent all shake or looseness, which, in an engine that works both in ascending and descending, would be destructive of its action. The two great links of the parallel motion are each composed of a strap or loop of iron, bent so as to make a double link, in the upper bend of which are two brasses for the pivots at the end of the beam, and at the lower end are two others, for the pivots which project on each side from a socket, which is fixed on the top of the piston-rod. The brasses of the latter joint are held in by wedges, or cross-keys, put through the two links at the lower end, so that by driving the wedges farther, the brasses can be drawn tight at pleasure. The two inside brasses, that is, the lower brass of the upper joint, and the upper brass of the lower joint, are kept extended to their proper distance by a piece of wood, or a light frame of iron, fitted in between them.

But we have not yet satisfactorily explained the action of the parallel motion. It is plain that the piston-rod must ascend and descend in a perpendicular right line, and also that the end of the beam must ascend and descend in the arc of a circle. When the beam rises into the position of *Plate VI.* from a horizontal one, it gives the piston-rod a tendency to move from its perpendicular towards the centre of the beam, which must move towards it, was not the link, *b*, attached to the beam and piston-rod by flexible joints; and while the lower end of the link, *b*, rises, the end of the bar or lever *m*, dotted, which is moveable on a fixed centre *m*, also rises at the same time, and the angle between *m* and *c* increases, and likewise the angle between *b* and *c* increases slowly; so that the vertex of the angle between *b* and *c* would move towards *B*, if the bar, *m*, was not confined to move round the fixed point or centre *m*, while the other end rises along with the rod *c*. While *m*, therefore, rises upon its centre, the adjoining bar, *d*, moves round the joint at its upper end, and draws *c*, and the lower end of *b*, from the centre of the beam, the angle between *d* and *c* increases, and the joint between *d* and *c* recedes from the centre of the beam; and as it cannot approach nearer to the joint between *b* and *c*, because of the rod *c*, it keeps *a*, and the bottom of *b*, in a perpendicular position; so that whatever tendency the joint between *b* and *c* has to approach towards the centre of the beam by the increase of the angle between *b* and *c*, is corrected by an equal tendency of the lever, *m*, to draw the angle between *d* and *c* in a contrary direction; but as the beam, *B*, falls into a horizontal position, all these motions are reversed. In adjusting the parallel motion for work, when the piston-rod, *a*, is found to rub most upon the side of the collar of the stuffing-box nearest to *m*, the fixed centre point, *m*, must be shifted a little in the contrary direction, *viz.* to remove it nearer to the centre of the beam, and in an opposite direction if it is found to rub on the other side.

That the nature of this parallel joint may be better understood, it is proper to observe, that all the bars which have been mentioned are made double, which cannot be shewn in the figure, and that the two levers, *m, m*, are placed at a sufficient distance asunder to allow the links *b*, and the rods *c*, to descend between them.

Of late years, the framing for the support of the engine has been wholly made of cast-iron. A very good form is to make the cistern, *L*, of cast-iron, all in one solid piece, and to fix the cylinder *A* upon it with four feet: a single column is then erected upon the end of the cistern *L*, to support the centre of the beam: the fly-wheel is supported by small cast-iron standards rising from the ground; and the centre of

the lever *m*, of the parallel motion, is supported by a small bracket or standard erected from the flanch of the cylinder. By this arrangement, all the parts of the engine are so united, that they cannot deviate in the least from their position, unless the parts are actually broken. An engine on this plan is fully described in the *British Encyclopædia*, vol. vi.

The engine represented in *Plate VIII. fig. 4.* is perhaps the most complete of all. It is of the form in which Messrs. Murray and Wood construct their engines, when they are not of a very large power.

Steam-Engines without Beams.—These have been made in a variety of forms. The simplest of all is to connect the piston-rod at once with the connecting rod, and to place the crank over the centre of the cylinder: the piston-rod must be guided by a parallel motion, or by sliders. The objection to this is, that the fly-wheel becomes elevated to too great a height for the communication of its motion, except in very particular circumstances, without shortening the connecting rod, which occasions the irregularity of the action of the crank to be greater than that of our table, in which the length of the connecting rod is supposed to be six times that of the crank, or three times the stroke of the engine, as a shorter cannot be made to work well. There is also a difficulty in balancing the weight of the piston-rod, connecting rod, and crank, and in giving motion to the air-pump. The balance-weight is usually placed on the rim of the fly-wheel; and the air-pump is either worked by a second smaller crank upon the axis of the fly-wheel, or by a short beam.

Engines of this kind are frequently placed with the cylinder horizontally, and for small engines this answers very well; but in large ones, the weight of the piston acting always at one side wears the cylinder irregularly. Mr. Murray included this plan in his patent of 1799, which we have before mentioned, for producing the rotatory motion without a crank; and he proposed to place rollers in the piston to bear it up.

Steam-engines with horizontal cylinders are used with the greatest advantage in steam-boats, as they can be made to lie low beneath the deck of the boat. Mr. Symington, we believe, first introduced this plan.

We have seen several engines working without a beam, in which the crank was placed immediately over the cylinder, and with the axis of the crank little more than its length above the top of the cylinder. For this purpose, the piston-rod is prolonged upwards to a length of three or four times the stroke of the engine, and the top is guided in a groove, or by a friction-wheel: near the upper end of it is jointed the connecting rod, which descends down to the crank-pin, situated behind the rod, and as close above the cylinder as it can turn round clear of its top. By this means, the ascent and descent of the piston-rod produce the rotation of the crank, the lateral deviation of the crank from the perpendicular being allowed for in the angle which the connecting rod makes with the prolonged piston-rod.

In this way the crank must be placed behind the piston-rod, or out of the line of it; but it is not then thought to work so well.

To remedy this the crank is made double, and the prolonged piston-rod has an opening in it for the crank-pin to pass through, and a connecting rod is placed on each side of the piston-rod, so that it is worked between the two. It is evident that the opening through the piston-rod must be a groove, equal in length to the stroke of the crank, so that the whole of the motion of the crank-pin, from one side to the other, can be admitted in the opening, without

influencing the piston-rod, except in its perpendicular ascent and descent.

The groove must be made wide, so that the pin cannot touch the sides of it. The pin is always retained in the middle of the groove by the connecting rods, of which there is one on each side, extending from the crank-pin to the top of the rod, which is prolonged in the line of the piston-rod, and is part of the frame forming the opening through which the crank-pin passes. It is evident, that in this way the opening cannot be a straight line, but must be formed to a portion of a circle, of which the centre is the joint that unites the connecting rods with the rod which prolongs the piston-rod, and in a line with it.

Another plan for applying the connecting rod immediately to the piston-rod, without the intervention of a working beam, is to have the axis of the crank placed immediately beneath the cylinder bottom, and a crank formed on it at each side: a cross-bar is placed upon the top of the piston-rod, long enough to reach over beyond the flanges of the cylinder; and from each end of it a connecting rod is suspended, the lower ends of which rods are jointed to the two cranks before-mentioned. This arrangement is, perhaps, the best of its kind, because the connecting rods are of a considerable length, without taking up any room.

Mr. Maudslay, of London, had a patent in 1807 for an engine of this kind, of which he has constructed a great number. *Plate VIII. fig. 3.* is a sketch of one of these. The specification states the invention to consist in reducing the number of the parts of the common steam-engine, and so arranging and connecting them, as to render it more compact and portable, every part being fixed to, and supported by, a strong frame of cast-iron, perfectly detached from the building in which it stands: it is not, therefore, liable to be put out of order by the sinking of the foundations. A is the cylinder, placed upon a frame of cast-iron plates B, B, which, at the same time that it elevates the cylinder to a sufficient height, forms the support for the axis of the fly-wheel D D. This axis has two cranks formed in it. E is one of the connecting rods, which, as before-mentioned, extends from those cranks up to the ends of the cross-bar, which is fixed at the top of the piston-rod, and which is guided in its ascent and descent by friction-wheels R, fitted upon it, and running in grooves N, N, formed in iron frames, which are placed in a perpendicular situation above the cylinder, and supported by a light iron framing O. Beneath the great frame, B, are placed two circular cisterns F, G, communicating by a pipe, which are for the condensing water: one has the cold-water pump in it, and the other contains the air-pump and condenser. These two pumps are worked alternately from the opposite ends of a short beam, H I, (*fig. 5.*) placed beneath the cylinder, and put in motion by a small crank, or eccentric circle, which is formed on the axis of the cranks, in the middle between the two cranks, and acts in a groove or opening made in a projecting arm, K, of the beam, a small parallel motion being applied to that end of the beam which works the air-pump. Instead of valves for supplying steam to the cylinder, a single cock, with four passages in it at L, performs the office of all the four valves: the lever of the cock is worked by a rod of communication from a handle, which is moved up and down every stroke, by the rod of the air-pump.

The condenser is a hollow cylinder, and the air-pump is placed within it, so that there is no necessity for a pipe of communication from the air-pump to the condenser: a small cistern, r, is fixed over the pump, to form the hot-well, and the discharge-valves of the pump are made in its lid or cover, and therefore in the bottom of the cistern.

A very ingenious method of converting the reciprocating motion of the piston-rod at once to a rotatory motion is represented in *Plate IX. fig. 5. Parallel Motions.* A toothed wheel, C, of a diameter equal to half the stroke of the engine, is made to roll round within a ring or fixed wheel A, having interior cogs, and being of a diameter equal to the whole stroke, or twice as great as the internal rolling-wheel C, which is carried round in a circular orbit, so as to work in the cogs of the ring, by having the crank-pin, R, for its centre of motion. By this means, every half turn of the crank will produce half a revolution of the centre of the small wheel in its orbit; and as it is all the time engaged by the cogs of the ring, it makes, during this motion, a whole revolution upon its own centre. The consequence of this is, that a point taken in the circumference of the small wheel, will travel up and down, across the centre of the interior ring, in every revolution of the small wheel in its orbit; that is, it will describe a right line, which is a diameter of the ring. A pin, F, being placed in a proper point of the circumference of the small wheel, and the top of the piston-rod being attached to it as it ascends and descends, will produce a rotation of the crank, upon the axis of which the fly-wheel is fixed.

This parallel motion is described in the article *Parallel Motion*. It has been employed by Mr. Murray in many of his engines: the objection to it is, that the cogs in time grow loose, and it then makes a very noisy and unsteady motion.

Bell-Crank Engine.—This is a very compact form of the steam-engine, which Messrs. Boulton and Watt began to make soon after the expiration of their patent.

The cylinder is supported by brackets from the cast-iron condensing cistern, and is placed over one end of it. The beam is formed like a bell-crank, that is, a right-angled triangle, the centre of motion being at the right angle, and the axis of it is supported by bearings screwed to the cistern at the lower side: and at the end opposite to that upon which the cylinder is placed, the horizontal arm of the triangle forms the working arm of the beam, to the extremity of which the power of the cylinder is applied. At the upper end of the perpendicular arm the end of the connecting rod is jointed, and extends to the crank, which is supported in bearings screwed to the cistern at the same end at which the cylinder is placed, the centre of motion being at the same level with the top of the cistern; and beneath the cylinder, the hypotenuse of the triangle of the beam forms a brace to strengthen it. Two of these beams are used, and are applied on opposite sides of the cistern, upon the same axis of motion, and are united together by cross rods, so that they move together in the same manner as if they were one. There are, therefore, two connecting rods and two cranks; but they are formed upon one common axis of motion, which is prolonged, to carry the fly-wheel. To connect the piston-rod with the ends of the arms of the beam, or what we have called the base of the right-angled triangle, a rod is fixed upon the top of the piston-rod, across the same, at right angles; and to the two ends of this two rods are linked, which descend to the beam, and are jointed to it at the ends. By this means, the ascent and descent of the piston-rod produce a corresponding motion of the beam upon its centre of motion, and the upper end of the perpendicular arm moves backwards and forwards, and by means of the connecting rods turns the cranks. The perpendicular arms of the beam are shorter than the arms to which the cylinder-rods are attached, so that the motion of the connecting rods, and the

sweep of the cranks, are less than in an engine where the arms of the beam are equal.

The rods which descend from the bar which is fixed across the top of the piston-rod to the ends of the beams, are of such lengths, that the obliquity which is occasioned by the circular motion of the ends of the beams is small, and the engine does not require any parallel motion to keep the piston-rod perpendicular. The same of the air-pump, which is placed in the middle of the cistern, and is worked by two rods jointed to the horizontal arms of the beams, at half the distance from the centre of motion at which the cylinder-rods are applied.

In these engines, valves are not used for admitting and taking away the steam from the cylinder; but to perform this office, a slider, invented by Mr. Murdoch, and represented in *Plate VII. fig. 9*, is used: the motion is communicated to the slider by an excentric wheel or rim, fixed on the fly-wheel. The bell-crank engine is very compact, and is well adapted for temporary use, as it stands wholly upon the cistern, and requires no fixing. We have seen it used in a steam-boat.

Different Methods of admitting Steam alternately into the Top and Bottom of the Cylinder.—The arrangement of the four valves invented by Mr. Watt has been described. This is now almost universally laid aside, in favour of more simple contrivances, though we think there is not any method so complete in its action, or so durable. For large engines, four separate spindle-valves are still used; but the method of lifting them is changed, the spindle of one valve being formed like a tube, for the spindle of the other to pass through. This plan is described in the specification of Mr. Murray's patent of 1801, the same which was for the improved air-pump.

The arrangement of the pipes and passages is the same, and the valves are situated in the same places; but the boxes which contain them, instead of being square, are cylindrical, and the spindles of the valves are placed concentric with the axis of the cylindrical box. The spindles of the two steam-valves are perforated through the centre, in the manner of tubes, and rise through a stuffing-box in the top of the box, and levers are there applied to lift them, instead of the lever or sector within the box, as described in the first engine. Through the tubular axis of the upper valves a small rod is conducted, which forms the spindles of the lower valves; and this junction is made tight by a stuffing-box formed at the top of the tubes. The operation of the valves is in every respect the same as the former; the only difference is in the mode of communicating motion to them from the outside, and at the top of the steam-box, both pair of valves being moved by rods through an opening in the lid of the box. See *Plate VII. figs. 4 and 5*.

This method is neat in its appearance, and answers equally well with the other when properly made, but it is not easy to make it like the other; for if the lid of the steam-box, when fastened on, deviates in the smallest degree from the central position of the valve-spindle which passes through its stuffing-box, both the valves will be prevented from applying themselves exactly to their seat. It is necessary for the two valve-seats, and the stuffing-box through the lid, to be made precisely on a common centre, line, or axis; and for this purpose, the upper part of the cylindrical box which contains the valves is bored out correctly within, and the conical sockets in which the bell-metal seats for the valves are to be placed, are bored at the same time; then the lid of the box which has the stuffing-box in it, being turned in the lathe, with a small projection beneath its flanch to drop into the

top of the cylindrical box, it will be certain to apply itself exactly in the centre of the box, and also perpendicular, when it is screwed fast down in its place, because the under surface of the lid, and the upper surface of the steam-box, have been accurately formed each of them concentric with, and perpendicular to, the axis of the valves; but it is necessary to use great caution in applying packing between these two surfaces, because it will yield unequally, if the screws at one side are screwed down more forcibly than those on the other side, and thus put the stuffing-box out of the perpendicular. To prevent this, Mr. Murray makes the lid of the box without any flanch, but it is exactly fitted into a small recess or rebate, formed for it all round at the top of the steam-box, by enlarging the diameter thereof a small quantity, as shewn in *fig. 15*. There is no packing applied to the joint, and it is then certain that the lid of the box will come to its true place. To prevent leakage, an iron ring is applied all round with a packing beneath it to cover the joint; and this packing and ring being screwed down by four screws makes it tight, and at the same time keeps the lid fast; but by releasing the ring, the lid can be lifted out, and the valves with it, to repair them. Mr. Murray's patent was set aside by a writ of *scire facias*, at the instance of Messrs. Boulton and Watt, who had previously practised some things contained in the patent; but we believe Mr. Murray was the first who made valves in the manner represented in the figure.

In small engines, the machinery now employed for opening and shutting these four valves is different from Mr. Watt's original engine, and much more simple. The motion is given by a rotative motion from the main axis of the fly-wheel: a wheel is fixed on the axis of the fly-wheel, and communicates motion by other wheel-work to a horizontal axis (*Plate VII. figs. 4 and 5*), upon which are two excentric wheels, which open and shut the valves alternately. Each of the boxes may be considered as being divided into three compartments by the two valves, and the steam is always admitted into the top of the upper box, where the upper steam-valve is situated; its use is to admit steam which comes from the boiler through the steam-pipe into the middle compartment of the box, which is the passage, 14, communicating with the top of the cylinder. In this compartment is the upper condensing valve *b*, which is moved by a rod passing through the rod or spindle of the upper steam-valve *g*: the valve *b* is for opening a passage from the top of the cylinder to the condenser, through the exhausting-pipe 13. In the same manner, the upper valve, *i*, of the lower box is called the lower steam-valve, and is for the purpose of admitting the steam which descends through the pipe, 12, into the bottom of the cylinder, below the piston. The valve *k* is for connecting the bottom of the cylinder with the condenser, and is therefore called the lower condensing valve.

The two rods, L, M, connect the four valves together in pairs; thus, the rod L has an arm projecting from it at each end, one at its top, fastened to the stem of the upper condensing valve, and the lower steam-valve is connected with it at its bottom; it will consequently, when it is lifted up by the excentric wheel, which is contained within an opening in the rod, open those two valves, and, by causing a vacuum above the piston, and a pressure of steam beneath it, will force it upwards to the top of the cylinder.

The rod M is connected with the upper steam-valve at the top, and with the lower condensing valve at the bottom. When it is lifted up by the excentric wheel, which works in an opening in the rod, it admits steam above the piston, and causes a vacuum below, in which situation the piston will descend. One of the rods which connect the valves must be allowed to descend by its weight an instant before the other is

lifted, otherwise the steam will have a free passage from the boiler to the condenser, a fault which is called blowing through, but is an operation practised every time at letting the engine to work, after having been some time at rest, for the purpose of expelling the air from the condenser. To blow through with this engine, all the four valves must be opened at once, which is done by lifting up the two rods, L, M, both together.

Fig. 16. represents an ingenious form in which Mr. Murray makes the excentric movements for working the valves, so that they shall move all at once, and not have the liberty of returning until the proper time.

The excentric triangle, A B, has its sides formed by arcs of circles: the axis of motion is made to coincide exactly with one of the angles, A, and the arc, B, is described from that centre. The excentric triangle is included within a parallel groove, C D, in an iron frame, in which it exactly fits, as in the figure. In this position, it is evident that the frame is immovable; it cannot ascend, because the circular part, B, bears against the lower side, D, of the groove; nor can it descend, because the angle, A, bears against the middle of the upper side C; at the same time, the excentric triangle can move round a certain part of a revolution before the rod will be moved at all, and then it will rise all at once; so that the middle of the lower side of the groove, D, will bear against the angle or centre of motion, A, and the upper side, C, will be borne by the arc, B, of the excentric triangle.

Four-passaged Cock.—Of late years, instead of the four valves invented by Mr. Watt, cocks and slides have been much used for alternately admitting the steam into the cylinder above and below the piston: they have the advantages of simplicity and cheapness, as one cock or slider is made to answer the purpose of the four valves.

What is called the four-passaged cock is the most readily applied to practice. This is represented in Plate VII. fig. 6. which is the cylinder of an engine made by Mr. John Dickson, who erected a great number exactly the same: the cylinder and its piston, with the lid and stuffing-box for the rod, are evident from inspection. The cylinder has a flanch or projecting ring round it, a little below the middle, by which it is held in a jacket or case of cast-iron *ccc*, which is constantly supplied with steam from the boiler by the pipe *e*: *ff* is a pipe, cast at the same time with the cylinder, leading from the top of it, and by a crooked passage to the cock E: *g g* is another similar passage from the bottom of the cylinder to the cock, and entering it diametrically opposite to the other passage: *h* is an opening, bringing steam from the jacket *ccc*, by means of a short pipe, not seen in the figure, being behind the cylinder, but cast at the same time with it, and joining at bottom to the flanch, by which it is held in the jacket. The bore of this short pipe is, however, continued through the flanch, and opens into the jacket; and when they are screwed together, the steam has free access from the boiler through the jacket into the short pipe, and from thence into the passage *h*, which advances horizontally forwards, as represented by the dark circle *h*, fig. 6, and turns into the cock; the short pipe has a thin circular vane in it, turning upon a pivot to form the throttle-valve, as we have before described.

When the steam is not made to pass through the jacket, the circular passage, *h*, may be considered as the continuation of the steam-pipe coming immediately from the boiler; and then the throttle-valve is placed in some part of the same pipe: *pp* is the pipe conveying the steam away from the cylinder to the condenser, which is of the ordinary construction. K is a handle fixed upon a spindle, on which is a rack, turning a cog-wheel upon the end of the cock E; this rack is partly seen in the drawing, but the pinion is

concealed. There are two pins fixed upon the rod of the air-pump, which take the handle K, as they move up and down, and thus turn the cock a portion of a turn each time: there is also a lever fixed on the spindle of the handle K, the ends of which stop against the ends of a crooked steel-spring screwed to the iron frame supporting the bearings for the spindle of the rack; so that the motion allowed thereby to the handle, K, and the rack, will turn the cock one-fourth of a whole turn, but no more. N is a cock communicating (when open) from the jacket *ccc* to the pipe *pp*, and thereby to the condenser, for the purpose of blowing through at first starting the engine. Now, suppose the steam flowing through the steam-pipe, *e*, from the boiler, it enters between the jacket, *ccc*, and the cylinder, passes through the short pipe and throttle-valve into the opening *h*, thence through the crooked passage in the cock E, to the pipe *ff*, leading to the top of the cylinder, thus causing the piston to descend. The steam in the lower part of the cylinder escapes, by the pipe *g*, through the other passage of the cock E, and by the pipe *pp*, into the condenser. When the piston arrives at the bottom of the cylinder, the pin on the air-pump rod carries down the handle, K, which, with its rack acting in the pinion on the end of the cock E, turns it into the position seen at fig. 7. The operation is now reversed, the steam enters from the jacket at *h*, through the cock E, and by the pipe *g*, into the bottom of the cylinder, forcing the piston to the top; at the same time the steam contained above the piston escapes through the opening *ff*, and the cock E, by the pipe *pp*, into the condenser. When the pin on the air-pump rod reaches the handle, K, in its ascent, it returns the cock to the position at fig. 6, when the operation is repeated.

Nothing can be more simple, or appear more perfect, than this contrivance, which was originally used by Papin in his air-cylinders; and Leupold, in his *Theatrum Machinarum Hydraulicarum*, vol. ii. has shewn the manner of its application to a high-pressure steam-engine.

In practice it has several objections. The pipe leading from the top and bottom of the cylinder to the cock is so much added to the volume of the cylinder, and the quantity of steam which they contain must be wasted every stroke without any advantage; but in the four valves, there is no farther loss than of the small quantity of steam which is contained in the passages 14 and 15, Plate VII. fig. 1. which are purposely made as narrow as they can be to admit the steam freely. Secondly: The passages cannot conveniently be made large enough to admit a full supply of steam, though it should be understood, that, in the other direction, they are three or four times as wide as they appear in the section, fig. 6.

In these engines the steam is always wire-drawn in passing through the passages; hence the steam in the boiler must be made stronger than it is intended to be used in the cylinder, to which, however, there is no objection, as it gives it something of the expansive action. Thirdly: These cocks do not wear equally, because there is much less surface exposed to friction in the part where the passages are; and as the surface which is interposed between the passages is so small, they leak immoderately from one passage to the other, unless the fitting of the cock is perfect. For these reasons, the four-passaged cocks have been confined to small engines, and principally those which work with high-pressure steam, because that will pass through very small openings.

Mr. Bramah has made several steam-engines, in which he employed a four-passaged cock on a construction somewhat different from the above. The steam from the boiler is made to enter into a hollow at the large end of the cone

of the cock, and to pass away to the condenser by a passage at the small end of the cone of the cock, which, by this means, is always pressed into its seat by the force of the steam acting upon a surface equal to the small end of the cock, from which the pressure is relieved. This keeps the cock always tight; and to prevent the moveable part from being fixed fast by the pressure, the cone is made much more obtuse than usual. The passages for the steam between the cock, and the top and bottom of the cylinder, are nearly the same as in *fig. 6*. Mr. Bramah had a patent for this in 1802; and another improvement was, that he made the cock to turn continually the same way round one-fourth at a time; by which means the same effects are produced as by turning it backwards and forwards, but the wear is rendered more equable.

Mr. Maudslay has adopted in his engines a four-passaged cock, in which the steam is made to press the cone into its seat.

Sliding-Valves by Mr. Murray.—With a view of remedying the inconveniencies of the four-passaged cock, the same effect has been attained by a plate sliding upon a flat surface, in which the passages are formed. A cylinder, with a slider upon this construction, is represented in *Plate VII. fig. 8*. It is used by Mr. Murray in small steam-engines, and found to answer the purpose extremely well, from the simplicity of its construction, and its durability, but, above all, from not being subject to wear or get out of order. *A A* represent the cylinder, inclosed in a cast-iron jacket, and surrounded with steam: it is furnished with a piston-rod, and stuffing-box, for the rod to pass through in the usual manner; *a* is the passage for the steam to enter the top of the cylinder; and *b*, the passage into the bottom, to admit steam below the piston. The steam is conveyed from the boiler by the pipe *B*, passes through the throttle-valve *c*, and into the steam-box *dd*, from which it is distributed to the cylinder by its different passages, as required. This steam-box is screwed by a flange against the flat surface of a pipe *D*, extending from the top of the cylinder to the bottom, and attached by dove-tailed joints to the two necks, *a, b*, of the cylinder. In the flat surface of the pipe *D*, there are three openings, *m, n, o*: the upper one, *m*, communicates with the top of the cylinder, through the passage *a*; the middle opening, *n*, communicates with the condenser by passing out sideways to the eduction-pipe, as at the dark circle at *p*; and the lower opening, *o*, communicates with the bottom of the cylinder by the passage *b*: *r* is the slider, made in the form of a box or cover, and ground round its edges, so as to fit exactly flat against the surface of the steam-pipe *D*, in which the three openings are made, and which is ground also. This slide is moved up and down by the small sector *s*, acting in the teeth of a rack, fixed to the back of the slide. The spindle of the sector passes through a stuffing-box in the side of the steam-box, and is moved on the outside by an eccentric wheel on the axis of the fly-wheel. The motion of the slider *r*, up and down, either connects the openings of the two passages *m* and *n*, or the two openings *n* and *o*. In the drawing, it is represented as connecting the upper passage *m* with *n*, which leads to the condenser, at the same time leaving the opening *o* uncovered, to receive the steam from the steam-box; consequently the steam enters below the piston, through the neck *b*, causing it to rise, and escapes from the top of the cylinder through the neck *a*; and by the connection of the opening *m* with *n*, it passes out at *p* into the condenser. Now if the slide is moved down, by turning the sector *s*, so that the lower passage *o* is connected with *n*, which leads to the condenser, the top

opening *m* will be open to the steam-box, and the steam will enter at the top of the cylinder, and cause the piston to descend, while the steam in the bottom of the cylinder will rush through the opening *b*, and by the connection of the passage *o* with *n*, it will pass into the condenser. In this manner, by alternately moving the slide up and down, this action is repeated, and the engine kept going.

In the figure of Mr. Murray's small engine (*Plate VIII. fig. 4*.) the eccentric circle *B* is plainly seen upon the axis of the fly-wheel; it operates exactly the same as a short crank, and has an iron frame or collar embracing it. By this a motion backwards and forwards is communicated by the rod *B S* to an axis, upon which are levers, giving motion to the lever of the sector, which moves the sliding-valve. The whole of the engine is upon an excellent construction: the air-pump is worked by the rod *R*, at the outer end of the beam.

In 1799, Mr. William Murdoch of Redruth, in Cornwall, obtained a patent for several improvements in steam-engines, amongst which is a simple construction of the steam-valve, or contrivance by which the steam is distributed to the cylinder, or withdrawn from it at the proper period.

This contrivance is a sliding-valve, which performs all the offices of the four valves which we have described for the double engine. Mr. Murdoch's patent has been adopted by Messrs. Watt and Boulton in most of their small engines, for many years past; and they have lately, with some alterations, introduced it into large engines. In *Plate VII. fig. 9*, *A A* is the steam-cylinder of the engine; *B*, the piston, and *C*, the piston-rod; *D* is the upper opening or steam-way into the cylinder; *F* is the steam-chest: in this is applied the sliding-tube, which performs the office of all the four steam-valves in the manner following. *G G* is a semicylindrical steam-pipe, (but which may be cylindric, triangular, or of any convenient form,) communicating with the steam-cylinder both at its upper and lower openings, and firmly fixed or connected to the steam-chest, or with the cylinder itself, where no steam-chest is used.

This tube has an opening, *H*, on its side, with a regulating valve for the admission of steam from the boiler; and another opening, *I*, at bottom, which leads to the condenser. At the top it is covered with a plate *T*, having a hole and stuffing-box to admit the sliding-rod *K*, which is jointed to, or connected with, an inner moveable pipe or tube *L M*, open at both ends. To one side of the sliding-tube are affixed the solid plates or valves *L, M*, intended to slide upon the plates at *D* and *E*, and occasionally to cover and uncover the upper and lower openings *D* and *E* of the cylinder. Opposite to these plates the remaining circumference of the tube, *L M*, is furnished with projections or flanches of brass, or other metal, with an interstice between them, to receive a packing of hemp, or other proper substance, which will permit the tube, *L M*, to move up and down, steam-tight, in the fixed tube *G G*. There are openings provided in the steam-pipe *G G*, which are shut with plugs or plates, screwed or otherwise fixed to it, which may be removed to repair the packing.

When the sliding-tube, *L M*, is in the position shewn in the figure, the steam enters through the steam-pipe *H*, and filling the interstices between the steam-tube *G G*, and the sliding-tube *L M*, passes into the cylinder at the upper opening *D*. As the lower opening, *E*, is open to the condenser, a vacuum will be formed within the sliding-tube *L*, and also below the piston, through the passage *E*, which is uncovered by the rise of the sliding-rod. In consequence, the piston descends; and when it has got near the bottom

of the cylinder, a bracket, attached to the top of the piston-rod C, strikes a projection upon the sliding-rod K, and causes the tube, L M, to descend a small quantity in the steam-pipe G. The sliding parts, L, M, by this motion, slide past the openings D and E of the cylinder, so as to be beneath them; and the steam, which is above the piston, issues at the upper opening, and passes down the inside of the tube L M, into the condenser. At the same time, the steam continuing to pass from the boiler through the pipe H, and the interstice between the steam-pipe and the sliding-pipe, enters the cylinder by the lower opening E, and forces up the piston and piston-rod, with its bracket, which, near the end of the ascending stroke, encounters another projection of the sliding-rod K, and raises the tube, L M, into its former position of the figure. The operations are then repeated. This is the plan used in Messrs. Watt and Boulton's bell-crank engine, and it is very good, because no steam is lost, as in all other constructions, where only one cock or slider is used.

If the sliding-plates, where they apply together, are made of steel, and hardened, they then wear extremely well. In some of Messrs. Watt and Boulton's latest engines, they have used similar sliders for large engines; but, in this case, they make the two sliders separate, being moved only by a rod of communication: because, if they were applied to a strong moving pipe, there would not be so great a certainty of their complete action, as the least deviation of the two sliders at the top and bottom of the cylinder would cause a great leakage.

There are many other methods of distributing the steam alternately to the top and bottom of the cylinder; but as we have described those which are brought to such a degree of perfection as to be commonly used, it is unnecessary to pursue the subject any farther.

Regulation of the Velocity of an Engine.—This is a matter of considerable importance. The most common method, as we have noticed, is by the governor or revolving pendulum; but there are others which, in particular circumstances, are very applicable. One is to have a small pump worked by the engine, and raising up water into a cistern, from which it runs out again in a constant stream. By this means, the water will accumulate and rise in the cistern, if the engine works rapidly, so as to pump more water into the cistern than will flow out of it in the same time; and, on the other hand, the surface of the water will sink in the cistern, if the engine works slowly; and a float being placed in the cistern, and connected with a wire to the throttle-valve, will regulate the motion of the engine. See REGULATOR.

In 1805, Mr. Job Rider obtained a patent for improvements in the steam-engine. These improvements consist, first, in lining the steam-cylinder with a soft metal, of a sufficient thickness to admit of finishing the inside of the cylinder of such metal, by drawing, boring, or otherwise; secondly, in applying a hollow piston-rod, answering the purpose of an eduction-pipe; thirdly, in the order of opening and shutting the valves; and fourthly, in regulating the speed of the engine by a pendulum. The nature of this latter contrivance is very ingenious, and may perhaps be understood from the following description. Upon an horizontal arbor, which we will denominate the main arbor, are placed three wheels, a drum or barrel, and a pinion: one of these wheels, that is to say, the main wheel, is fitted by means of a socket upon the main arbor, so as to turn round upon that arbor, and has teeth both upon the exterior and interior periphery of its rim. Within the circle of the interior cogs of this wheel a pinion is fixed to the arbor, its diameter being one-third of the interior diameter of the main wheel;

and this pinion has teeth surrounding its convex surface. The moveable barrel turns freely upon the main arbor; its diameter is rather less than the exterior diameter of the main wheel, and it carries a cord, with a weight hanging at its end, acting like a clock-weight. Besides this, the ends of the barrel are pierced with two orifices, each at about half the exterior radius of the main wheel from the arbor; these holes serving as bushes or pivot-holes, wherein an arbor turns, carrying a wheel, of which the diameter and number of teeth are equal to those of the pinion: the latter wheel may be called the barrel-pinion; its teeth work in the teeth of the pinion, and also in the interior teeth of the main wheel. By these means, the barrel may be turned round upon the main arbor, while the arbor itself is turned by the pinion, which is acted upon by the barrel-pinion, at the same time that this pinion acts upon the interior teeth of the main wheel. The external teeth of the main wheel turn the pinion of a scapement-wheel and pallets, nearly similar to those in Graham's dead-beat. Near one end of the main arbor there is a ratchet-wheel, and wheel and click; and near the other end a wheel, which is acted upon by an endless screw upon a horizontal shaft, worked by the general operation of the steam-engine.

This arrangement serves to regulate the rate of the engine's motion; for the turning of the worm-wheel, by the general motion of the engine, causes the weight to be raised which hangs to the cord that winds upon the barrel; and this weight is connected to one end of a lever, the other end of which is attached to the steam-valve in such a manner, that the degree of opening of that valve depends upon the altitude to which the weight is raised. The aperture of this valve is formed like an inverted cone; and while this valve shuts and opens twice at every stroke, the lever does not prevent such opening and shutting, but merely limits the extent of the opening by the springing up of a rod connected with it. By this contrivance it happens, that when the weight is highest, the valve is least opened; and when the weight is lowest, the valve is most opened. Hence it is evident, that should the engine wind up the weight, by turning the worm faster than the pendulum permits it to descend by the turning of the barrel, the aperture of the valve will be contracted; and *vice versa*. Little power is lost by these means, and the speed of the engine can be accurately regulated by properly adjusting the length of the pendulum, and the numbers of teeth in the wheels and pinions. As to the ratchet-wheel and click, their sole use is to prevent the weight from drawing the line off the barrel, when the worm-wheel is thrown out of gear. We have not had an opportunity of seeing one of these machines at work, but think it would operate very well.

Mr. Cartwright's Engine.—In giving the history of Mr. Watt's inventions, we mentioned that the condensation by external cold was one of his first ideas, and given up, because he found it better to employ injection. We have also described his single engine, in which the piston rises in vacuo. In 1797, Mr. Cartwright took out a patent for improvements in the construction of steam-engines, in which the condensation is performed by the application of cold to the external surface of the vessel containing the steam.

The manner Mr. Cartwright effects this is by admitting the steam between two metal cylinders, lying one within the other, and having cold water flowing through the inner one, and surrounding the outer one. By these means, a very thin body of steam is exposed to the greatest possible surface of cold metal. By means of a valve in the piston, there is a constant communication at all times between the condenser and the cylinder, either above or below the piston.

ton; so that whether it ascends or descends, the condensation is always taking place, in the same manner as Mr. Watt's engines, where the piston rises in vacuo. But what was probably esteemed one of the most important circumstances attending the mode of condensation, was the opportunity it affords of substituting ardent spirit, either wholly or in part, in the place of water, for working the engine. For as the fluid, with which it is worked, is made to circulate through the engine without mixture or diminution, the using alcohol, after the first supply, would be attended with no very great expence; on the contrary, the advantage was expected to be great, even equal to the saving of half the fuel. If, indeed, the engine could be applied, as Mr. Cartwright occasionally purposed, both as a mechanical power and as a still at the same time, the whole fuel would be saved.

Mr. Cartwright has been very attentive in simplifying all the other parts of the engine, his engine having only two valves, and those are as nearly self-acting as may be: in consequence, the engine is rendered applicable to purposes requiring only a small power, and for which any other engine would be too complicated and expensive. See a figure of Mr. Cartwright's engine, *Plate V. fig. 8*, where *a* is the cylinder, which is supplied with steam from the boiler through the pipe *b*; *c* is the piston in the act of going up; *d* is the eduction-pipe that conducts the steam into the condenser *w*, which consists of two cylinders, one within the other, leaving a small space between them, into which the steam is admitted; while the inner cylinder is filled with cold water, and also the external cylinder surrounded by the same; so that, by this means, a very large surface of steam is exposed to the cold of the water, though no water is suffered to come in actual contact with it.

To the bottom of the piston *c* is attached a rod, with another piston *e*, working in the barrel *d*, which is in reality the air-pump of the engine, and has a pipe, *f*, to the condenser. When the piston *c* arrives at the bottom of the cylinder, a valve, *r*, which is in the piston is opened, by its tail pressing against the bottom of the cylinder, which opens the communication from above the piston to the condenser, while the spring *k*, fixed to the rod of the piston, presses down the tail, and shuts the steam-valve *t*, which admits the steam from the boiler. The steam therefore within the cylinder, both above and below the piston, being condensed, runs through the lower pipe, *f*, to the air-pump, and the piston, being relieved from all pressure, is drawn up in the cylinder by the fly-wheel. The piston *e* of the air-pump arriving at the top of the barrel, in which it works at the same time with the working piston *c*, draws the air from the condenser, and on its return at the next stroke, presses upon the condensed water, shuts the valve *f*, and forces the water up the pipe *g*, into the box *b*: the air which is disengaged from the water rises to the top of the box, and by its elasticity forces the water through the pipe *i*, which carries it back again to the boiler. When the air accumulates in the box to such a degree as to depress the water, the ball cock falls with it, and opens a valve in the top of the box, which suffers some of the air to escape.

When the piston arrives at the top of the cylinder, it presses up the steam-valve *t*, which admits the steam again from the boiler, to force it down as before; and the valve, *r*, in the piston shuts by pressing up beneath the top of the cylinder. The pressure of the steam is now above the piston, and a vacuum beneath; the piston therefore descends, and when at the bottom, shuts the steam-valve *t*, and opens the valve, *r*, in the piston.

When all the steam in the upper part of the cylinder is

condensed, the motion of the fly attached to the machine brings the piston up again, its valves now remaining shut by their weight.

l and *m* are two cranks, upon whose axes are two equal cog-wheels working in each other, for the purpose of converting the perpendicular motion of the piston-rod into a rotatory motion for working the machinery attached to it.

As it is evident, from its construction, that the whole of the steam is brought back again into the boiler, it affords the means of employing ardent spirit instead of water, and thus saving a great deal of fuel.

Cartwright's Metallic Piston.—The most valuable part of this engine is in the construction of the piston, which Mr. C. made wholly of metal, so as by means of springs to fit the cylinder very exactly.

This not only saves the expence and trouble of packing, which must be frequently renewed in all other engines, but also a great deal of steam, on account of the more accurate fitting of the piston. This piston is made in the following manner: Two metal rings are ground, by means well known to good mechanics, into the cylinder, so as to fit it as perfectly as art and industry can make them; that is so well, that no steam can pass between them and the cylinder: their upper and under sides are also ground perfectly flat, and applied one upon the other. Though not absolutely necessary, for greater security two other rings are fitted to the inside of these. On the upper rings is placed a plate of metal, also ground perfectly flat, and of such a diameter as almost to fit the cylinder. A similar flat plate is placed below the under ring; and the two plates, with the rings between, are attached firmly to each other by means of the piston-rod that passes through them, and they thus form a shell, in which the other rings are contained.

It is plain then, supposing neither the outside rings nor the cylinder are able to wear one another, that such a piston would remain steam-tight; but as constant friction must inevitably tend to enlarge the cylinder, and diminish the diameter of the rings, the piston, after some time, would cease to fit, if a contrivance had not been made to remedy the evil. The rings are each of them cut into three pieces, and in cutting them, such a portion of the metal is taken away as to leave room to introduce, between two of the pieces, a spring in form of the letter V, the open end of which is placed outwards, almost close to the circumference; by which means the two pieces against which the two sides of the spring act are pressed, in the direction of the circumference, against the ends of the third piece; so that the three pieces are thus kept so uniformly in contact with the cylinder, that the longer the machine is worked the better the rings must fit.

To prevent steam passing through the cuts in the rings, the solid parts of the upper rings are made to fall upon the divisions and springs of the under ones, so as to form a break joint.

The stuffing-box round the piston-rod was proposed to be done in the same manner.

The metallic piston has been found advantageous, and Mr. Woolf uses it in his engines, which is the greatest trial of a piston, because of the rarity of the steam. *Plate VII. figs. 10 and 11*, represent a piston of a four-horse engine, which was made by Messrs. Lloyd and Ostel. A is the piston-rod, and B C the solid metal of the piston, firmly fitted and keyed to it: the lower edge, C, of the plate, B, is made very nearly to fit to the cylinder; but for the actual fitting, dependence is placed on the four rings, D, fitted one upon another, and each divided into four segments, as shewn by *fig. 10*. The interior surface of these rings is made rather conical, and a second set of smaller rings, E, is accurately

fitted within side of them. These rings are divided, like the former, each into four segments, and the springs are applied behind them, as shewn in *fig. 10*, in a better manner than the original, which were like the letter V. E E is the cover-plate, which is screwed on over all the segments, to confine them: it presses down the interior rings into the exterior, and the contact between them being by a conical surface, the effect is to spread the outer rings a small quantity, and enlarge them till they exactly fill the cylinder. The dark mark beneath the lowermost interior ring E, is a piece of felt or pasteboard, which sustains the rings, and prevents them from descending, except when the screws are tightened, or the rings would expand with too much force into the cylinder.

Woolf's improved Piston.—The common method of packing the piston of a steam-engine with hemp, will be so well understood after what we have said, that a particular description of it in this place is not necessary; suffice it to say, that the hollow part round the piston is filled with rounds of hemp, loosely twisted into a soft rope, which is pressed into a pretty compact form by a ring, and worked down by screws distributed round the ring, which work into the body of the piston; by this means the packing is made to fill the diameter of the cylinder pretty closely, and to prevent, while the packing remains sound, any steam from passing between the piston and the cylinder. In the usual method, whenever the piston, by continued working, becomes too easy, and so occasions a waste of steam, it is necessary to take off the top of the cylinder, even when fresh hemp or packing is not wanted, merely to get at the screws, which serve to force the upper ring nearer to the bottom of the piston, by which means the packing is forced outwards against the side of the cylinder.

This being heavy laborious work, it is generally deferred, by the man that attends the engine, as long as the engine can possibly be made to work without taking this trouble; and in consequence of this neglect, a great and unnecessary waste of steam is occasioned, and a waste of fuel in proportion.

Mr. Woolf's improvement on the piston is such as to enable the engine-man to tighten the piston, without the necessity of taking off the cover of the cylinder, except when new packing becomes necessary. He accomplishes this by either of the two following methods. He fastens on the head of each of the screws a small cog-wheel, *c, c, c, c*, (*Plate VII. figs. 12 and 13*), which wheels are all connected with each other by means of a central wheel *d d*, which works loose upon the piston-rod in such a manner, that if any one of the small wheels and its screw be turned, it turns the central wheel, and the latter turns all the other three wheels and screws. That one which is to be first turned is furnished with a projecting square head *f*, which rises up into a recess in the cover of the cylinder. This recess is surmounted by a cap or bonnet, which being easily taken off, and as easily put again in its place, there is little difficulty in screwing down the packing at any time, by applying a key to the square head of this screw. The parts are so clearly expressed in the plates, that no farther description is necessary to make any person comprehend it.

Mr. Woolf contrived another method for small pistons, which is similar in principle, but a little different in construction. Instead of having several screws, all worked down by one motion, there is in this but one screw, and that one is cut upon the piston-rod itself; on this is placed a wheel of a convenient diameter, the centre of which is furnished with a female-screw. This wheel is turned round, *i. e.* screwed down by means of a pinion, which is furnished with a square projecting head, rising into a recess of the kind already de-

scribed. The upper ring of the piston is prevented from turning with the wheel by means of two steady pins.

High-Pressure Steam-Engine.—The operation of the high-pressure steam-engine is effected solely by the expansive force of steam, which is not condensed in the manner of the atmospheric or Watt's engine. The steam being raised in the boiler, and heated far beyond the boiling point, is made to acquire a great expansive force, and exert an immense pressure to escape from any vessel in which it is confined, even as great as four or five times the pressure of the atmosphere. This steam being allowed to enter into one end of a cylinder, while the other end of the same communicates with the open air, it will exert a force upon the piston of the cylinder, and move it from one end to the other. This is the principle of the high-pressure engine, which has been much introduced of late, on account of some advantages which it possesses in particular situations over other engines: first, from the simplicity of its construction and cheapness; secondly, the small space which it occupies; thirdly, its requiring no condensing water, which in some situations is very difficult to procure, and in one instance is altogether impracticable, *viz.* for drawing of carriages, for which purpose this engine has been successfully used. To set against these advantages, the high-pressure engines are extremely liable to blow up, if not attended very carefully, for they are frequently worked with a pressure of from sixty to eighty pounds on the square inch. These engines require a greater quantity of coals, in proportion to the force exerted, than the engines of Mr. Watt, and consequently are not worked with advantage in a situation where coals are dear.

The first application of high-pressure steam to an engine, is what we find described in 1724, by Leupold, in his *Theatrum Machinarum Hydraulicarum*, vol. ii. p. 93. He ascribes the invention to Papin, on account of his having given him the idea of applying the expansive force of steam for the purpose of raising water, and also because he took the construction of the four-passaged cock, to communicate alternately with two cylinders, from Papin's air-machine, which has been described in the former part of this article. The engine described by Leupold consists of two single cylinders, placed at some distance from each other, with a piston fitted to each, and applied to two separate beams, which at the opposite ends work two forcing-pumps. Between the two cylinders is the four-passaged cock, the same as described in *Plate VII. Steam-Engine, fig. 6*, for admitting the steam from the boiler alternately into the bottom of each cylinder, or allowing it to escape from the cylinders into the air. The boiler is situated beneath the two cylinders, and communicates with the cock by a short upright pipe. The action of this engine is very simple: the steam being raised very strong in the boiler, is allowed to enter through the cock into the bottom of one of the cylinders, at the same time that the air or steam escapes from the bottom of the other, through the other passage of the cock into the open air. In this way, the pressure of the steam causes the ascent of the first-mentioned piston, and the other descends by its counter-weight. By turning the cock round one-fourth, the operation is reversed, so that the steam enters the bottom of the second cylinder, and the steam which was contained in the first escapes through the passage of the cock into the air.

The next proposal for a high-pressure engine is Mr. Watt's patent of 1769. See the fourth particular of his specification, which we have given, but we do not know that he ever practised it, finding his own invention so much superior.

The high-pressure engines at present in use were introduced by Mr. Trevethick, in conjunction with Mr. Vivian, who obtained a patent for the same in 1802: this was prin-

especially for their application of the engine to the purpose of driving of carriages upon rail-roads.

This engine containing no material parts which are not used in other engines, and before described, it may be explained without a drawing. The boiler consists of a large cylinder of cast iron, made very strong, and placed with its axis horizontally upon short feet or pillars of cast iron: the boiler has a flanch at one of its ends, to screw on the end or cover, which has the requisite openings for the fire-door, the man-hole, the exit for the smoke, and the gauge-cocks. The fire is contained within the boiler, in a cylindrical tube of wrought iron, which is surrounded with water on all sides, in the same manner as the fire in Mr. Smeaton's portable engines, of which we have given the description; but there is a little difference in the application: one end of this tube is flanch'd to the end or cover of the boiler, and is divided into two parts, by having the fire-grate extended across it: the fire-door closes the opening in the upper half, which is the fire-place, the lower half forming the ash-pit: the tube extends nearly to the end of the boiler, where it is reduced in size, then doubles, and returns back in a direction parallel to the first tube or fire-place to form the flue or chimney, till it arrives at the end or cover of the boiler, through which it passes at the side of the fire-door, and a flue is then conducted from it into the chimney, to carry off the smoke.

At the part where the flue enters the chimney is a small door, to remove any soot that may have accumulated. On the top of the boiler is a safety-valve, kept down by a lever and weight, to allow the steam to escape in case it becomes so strong as to endanger the bursting of the boiler. The steam-cylinder stands in a perpendicular direction, and is inclosed within the boiler, except a few inches of its upper end, at which the four-passaged cock is situated, and the flanch which screws on the lid, with the stuffing box for the piston-rod to pass through. The boiler has a projecting neck, into which the cylinder is received, and it is fastened in its place by a flanch round the upper end of the neck of the boiler, which is united by screws to a flanch projecting from the cylinder at about one-third from its top flanch. The upper end of the piston-rod is fastened to the middle of a cross-bar, which is placed in a direction at right angles to the length of the boiler, and guided in its ascending and descending vertical motion, by sliding upon two perpendicular iron rods, fixed to the boiler, parallel to each other, being connected together at top, and firmly supported there by two diagonal stays, extending from the other end of the boiler, and secured to the flanch, which screws on the end of the boiler. At the ends of the cross-bar of the piston-rod the two connecting rods are jointed, and the lower ends of them are connected with two cranks, fixed upon an axis, extending across beneath the boiler, and under the centre of the cylinder: the axis is supported in bearings made in the legs which support the boiler, and the fly-wheel is fixed in it. One of the cranks is formed by a pin which is fixed into the arm of the fly-wheel, at the same radius as the opposite crank. The fly-wheel is situated close to the side of the boiler, and the pin for the other crank is fixed into the arm of a large cog-wheel, fixed on the axis of the fly-wheel, at the opposite side of the boiler. This cog-wheel communicates the power of the engine to other cog-wheels. As the piston is alternately forced up and down by the pressure of the steam, it carries the cross-bar with it, and by the connecting rod turns the two cranks, together with the fly-wheel and cog-wheel.

It now remains to shew the means by which the steam is brought to act alternately on different sides of the piston. On one side of the cylinder, just above the flanch which fixes it into the boiler, and beneath the top

flanch, which fastens down its lid, is a protuberance of cast iron, to contain the four passages and the cock, similar to that shewn in *figs. 6 and 7*. One passage rises directly from the boiler, and brings steam to the cock at one side, to be distributed either to the top or bottom of the cylinder, according to the position in which the cock stands. A second passage rises from the upper side of the cock, and proceeds to the top of the cylinder, for admitting steam above the piston. The third passage from the under side of the cock connects with the bottom of the cylinder by a pipe cast close to the side thereof, and descending to the bottom. The fourth passage from the cock is on the opposite side to where the steam enters from the boiler, and this passage is open to the waste-pipe, which carries the steam into the external air, and allows it to escape after it has passed through the engine. Now suppose the passage leading to the top of the cylinder, and that one which brings steam, are from the boiler to be connected with the cock, and the passage from the bottom of the cylinder to be connected with the waste-pipe, the steam will enter above the piston, and force it down, at the same time that the steam in the bottom of the cylinder will escape by the connection of the waste-pipe with the open air.

When the piston arrives at the bottom of the stroke, the cock is turned one quarter round, by means of a rod jointed to the cross-bar of the piston-rod, and descending perpendicularly, being guided at bottom by passing through a piece of iron screwed to the flanch of the cylinder: this rod has two pins projecting from it, which move the handle of the cock up and down alternately; by this the cock is turned on the completion of the descending stroke, so that the passage to the bottom of the cylinder is connected with the boiler, and that from the top with the open air: the steam in consequence enters below the piston, and forces it up, passing out from the upper part of the cylinder into the open air at the same time. In this manner the motion of the engine is kept up by the pins alternately turning the cock, first at the top of the stroke, and then at the bottom.

The boiler is supplied with water, as fast as it evaporates, by means of a small force-pump worked by the engine; but as it would be a great loss of heat to inject cold water at once into the boiler, it is first rendered nearly or quite boiling by a very simple contrivance. The waste-pipe, which conveys the steam away from the cylinder after having performed its office, is inclosed within an external pipe or jacket, leaving a space of about an inch all round; through this space the cold water is forced to enter at one end by the small force-pump, and the boiler is supplied with water by a branch from its other extremity. By thus carrying the water some distance in contact with the hot waste-pipe, through which the steam passes, it is heated, and a considerable quantity of heat is saved, which would otherwise be lost.

The velocity of the engine is regulated, or its motion can be entirely stoppt, if required, by a cock situated in the first passage from the boiler to the four-passaged cock, so as to regulate the passage between the boiler and the cock. The handle of this cock may be connected with a governor, similar to those used in other engines. The construction of the four passages and cock is exactly similar to what is represented in *fig. 6. Plate VII.*, except that it is placed near the top of the cylinder, because all the lower part of the cylinder is contained in the boiler, and also that the axis of the cock is directed to the centre of the cylinder. High-pressure engines have been sometimes made with beams and parallel levers; but more frequently the cylinders have been placed horizontally, and the piston-rod jointed at once to the connecting rod.

Several very terrible accidents have occurred from the

bursting of high-pressure boilers, either from their being made too weak to resist the force they are intended to bear, or from some mismanagement, as loading the safety-valve too much. Some years ago, an engine that was employed to drain water from the tide-mills, while building between Woolwich and Greenwich, was blown up by overloading the safety-valve, when several people were killed. Many provisions have been made to guard against these accidents by Mr. Trevethick, who first brought the high-pressure engines into use: at first he proposed inclosing the safety-valve in such a manner, that no one could get access to it to increase the load beyond what was intended to be employed. Secondly, he drilled a hole in the boiler, which he plugged up with lead, at such a height from the bottom, that the boiler could never boil dry without exposing the lead to be melted, and consequently making an opening for the steam to escape. This contrivance is calculated to prevent the boiler being burst by suddenly forcing water into it, when it has been allowed by carelessness to boil dry, and become red-hot. A metal plug should always be rivetted into such a boiler. The plug should be made of such a composition of the fusible metal, that it will melt whenever the contents of the boiler attain that degree of heat which produces steam of a dangerous elasticity. Another precaution which should always be taken, is to have two safety-valves fixed in different parts of the boiler; so that if by any accident one of them becomes fixed fast in its seat by rust or other means, the other will be in a state to act, thereby diminishing the chance of an accident to half; and the larger these safety-valves are made, the more certainly they will operate. The mercurial steam-gauge used in most engines is a long curved tube, or inverted siphon, in which the mercury rises by the force of the steam, and indicates the pressure. If this kind of steam-gauge is applied to the high-pressure engine, it requires a very long tube, which is an additional security against the bursting of the boiler, because the mercury will be blown out of the tube, and permit the steam to escape when the pressure is too great.

Before the boiler of a high-pressure engine is set to work, it should be proved effectually, first by drilling small holes through it at different places, to actually measure the thickness of the metal, and ascertain that it is equal throughout; and then it should be proved by injecting water into it, until the pressure lifts the safety-valve, when loaded considerably more than it is intended to be when the engine is set to work; but this proof should not be too severe, because the metal may be weakened, although it is not burst, by the proof; and, in consequence, may afterwards burst with a much less pressure of steam. At the same time, the engineer who undertakes to make these engines, should fully inform himself of the real strength of metal boilers of determinate thicknesses, which could be easily done, without danger, by injecting water into the boilers until they actually burst. We do not know if such experiments have ever been made; and in those boilers which have been burst by the explosion of steam, the pressure at the moment of the accident has not been known.

We have an account of a trial of a small high-pressure engine made in 1804, in Wales, to ascertain its powers to raise water: the cylinder was 8 inches in diameter, and $4\frac{1}{2}$ feet stroke; it worked a pump $18\frac{1}{2}$ inches in diameter, and $4\frac{1}{2}$ feet stroke, which raised water 28 feet high. It worked at the rate of 18 strokes per minute, and consumed about 80 lbs. of coals per hour: this, when reduced, is about $17\frac{1}{2}$ million pounds raised one foot high for each bushel. Thus, the weight of the column is 3266 lbs. for the area of the pump ($18.5 \times 18.5 = 342.25 \times .7854 =$) 268.8 square

inches $\times .434$ lbs. = 116 $\frac{1}{2}$ lbs. the weight for every foot of the column $\times 28$ feet = 3266.5 lbs. the total weight of the column. The motion of the piston per minute is ($4\frac{1}{2} \times 18 =$) 81 feet, or 4860 feet per hour $\times 3266.5$ lbs. = 15,875,160 lbs. raised one foot high per hour. The coals consumed in the hour is 80 lbs.; therefore say, as 80 lbs. : 15,875,160 lbs. :: 88 lbs. : 17,462,676 lbs., the number of pounds raised one foot high for each bushel of coals. The area of the piston is ($8 \times 8 = 64 \times .7854 =$) $50\frac{1}{4}$ square inches, and the load $3266.5 \div 50\frac{1}{4} = 65$ lbs. pressure per square inch on the surface of the piston.

Manufacture of Steam-Engines.—The great demand for these machines, which has taken place since their value has been so fully understood, has occasioned them to be manufactured in the large way by several engineers, who adopt the same system as is pursued in making of watches and clocks, viz. that of having workmen instructed in making the separate parts, and employing machines and tools for every operation which admits of such aid. The first of these manufactories is that of Messrs. Watt and Boulton, at Soho, near Birmingham, sons of the inventor and his associate, who established the manufactory about 1775; and until the expiration of Mr. Watt's patent in 1800, it was the only place where his engines were made. It has continued ever since to furnish the greatest proportion of engines, as well for this country as abroad. There are now other manufacturers who approach the original in the beauty and perfection of the workmanship.

Since the expiration of the patent, there has been a total change in the manner of constructing and putting together every part of the engine, and many advantageous improvements have been made, as far as respects the durability and accurate performance of the machine; though nothing, except the second cylinder of Hornblower and Woolf, has been added to Mr. Watt's engine since he first brought it to a standard, by which its powers are at all increased, with respect to the consumption of fuel, but rather the contrary. At the first establishment of these manufactories, on the expiration of Mr. Watt's patent, many ingenious mechanics attempted to improve the structure of the machine, and the records of the patent office contain more upon this subject, than any other. All kinds of parallel motions have been tried; cylinders have been inverted, placed horizontally, made of long and short proportions; large air-pumps have been used; and for the minor parts, such as valves, and the machinery for actuating them, scarcely two following engines were made alike for many years, until by the result of a vast deal of invention and experience, those methods which we have described became settled into established forms; but none of them are superior to the original of Mr. Watt's. Respecting parallel motions, and the proportions of the parts, no methods have been found so good as the original engine; and we accordingly find, that all the most established and experienced manufacturers make engines which are not altered in any great feature from Mr. Watt's original engine, with a beam and parallel motion acting on a simple crank; and they give them all the advantages which can be derived from superior workmanship, and improved methods of putting the parts together, which experience has pointed out.

Messrs. Fenton, Murray, and Wood, of Leeds, Yorkshire, are the manufacturers of the most established reputation after Messrs. Watt and Boulton. The engines they send out cannot be excelled in beauty and perfection of workmanship, and they perform as well as any others. Their factory at Leeds is very extensive, and provided with every convenience for making all the parts of the engine in the best manner, and with the least labour. They have three

steam-engines in the works, one for boring cylinders, and turning large lathes; a second for turning small lathes, grinding, drilling the centres of wheels, tapping screws, &c., and for blowing the furnaces of the foundry; and a third engine for working a great forge hammer, by which the heavy wrought iron work is forged. The boring machines for cylinders, of which they have three in number, are very capital, as by an ingenious movement, invented by Mr. Murray, for drawing the borer through the cylinder, it is made to advance regularly from one end to the other, without any interruption. These machines are worked by a separate steam-engine, which is never stopped during the operation of boring a cylinder through, as it is found to make a sensible mark or ring if the motion is stopped. The best means are also taken to prevent the cylinder from changing its figure by its weight, or by the pressure of the parts which hold it in its position. The whole of the factory is lighted by gas lights in winter time. The boilers are manufactured by the aid of several machines to cut out the plate, pierce the holes, and bend the joints. Before any of the smaller engines are sent away, all the parts are put together in a building on purpose, where there are boilers fixed and they are actually tried, to insure that every part is perfect: they are then taken to pieces, with marks and directions for putting them together, and packed up for carriage, which is very easy, as there is a canal at the gates, which has communication by water to every part of England. For such engines as are too large to be put to work at the factory, workmen are sent out with them, to assist and direct in setting them to work.

In London, Mr. Maudslay has made many very excellent steam-engines upon the plan represented in our sketch; but his best engine, which is in the saw-mill at Woolwich, is with a beam upon Mr. Watt's plan. He has lately made a large engine for a steam-boat invented by Mr. Brunel, which has two cylinders acting alternately upon different cranks, formed upon the same axis at right angles to each other, so that the motion is continued without a fly-wheel: one boiler is placed between the two cylinders, and one air-pump and condenser exhausts them both. By this means a powerful engine is contained in a small space, and is not heavy to load the boat.

Some engineers of Manchester make very good steam-engines, chiefly for the great cotton-mills. At most of the iron furnaces in the country, steam-engines are now made, and some of them produce very capital engines, as at Butterly in Derbyshire, Low Moor in Yorkshire, and others. Their workshops are in general managed by engineers who have been educated at Soho, or at Leeds. Mr. Woolf's engines are made in London by Mr. Edwards, and by himself in Cornwall.

Rotative Steam-Engine.—The reciprocating motion of a steam-engine has always been considered as a great defect; for though all irregularity of motion can be obviated by connecting it with a fly-wheel, yet a great mass of matter must always be kept in a constant succession of changes from rest to motion; and the irregularities which this would produce, can only be governed by putting a great mass of matter in the fly-wheel, and causing it to move with a rapid motion, so that its momentum or vis inertia shall be vastly greater than that of all the reciprocating parts together. With a view of obviating this objection, and of obtaining the action of steam by more simple machinery than a cylinder and piston, many attempts have been made to produce a circular motion at once by the steam. It has been made to blow on the vanes of a wheel of various forms. But the rarity of steam is such, that even if none is condensed by the cold of the vanes, the impulse is exceedingly feeble, and the

expenditure of steam, so as to produce any serviceable impulse, is enormous. Mr. Watt, among his first speculations on steam-engines, made some attempts of this kind; but he has not given such a description of the valves for this purpose, as to enable an engineer to construct one of them. From any guess that we can form, we think the machine very imperfect. One of Mr. Watt's first trials was uncommonly ingenious; it consisted of a drum, turning air-tight within another, with cavities so disposed, that there was a constant and great pressure urging it in one direction. But no packing of the common kind could preserve it air-tight with sufficient freedom of motion. He succeeded by immersing it in mercury, or in an amalgam which remained fluid in the heat of boiling water; but the continual action of the heat and steam, together with the friction, soon oxydated the fluid, and rendered it useless. He then tried Parent's or Dr. Barker's mill, inclosing the arms in a metal drum, which was immersed in cold water. The steam rushed rapidly along the pipe which was the axis, and it was hoped that a great re-action would have been exerted at the ends of the arms; but it was almost nothing. The reason seems to be, that the greatest part of the steam was condensed in the cold arms. It was then tried in a drum kept boiling hot; but the impulse was very small, in comparison with the expenditure of steam: this must be the case.

Mr. Watt has described in his specification of 1782, lodged at the patent office, some more perfect contrivances for producing a circular motion by the immediate action of the steam. One of these produces alternate motion upon a centre, and is analogous to the double engine; another produces a continued motion. See his first specification of 1769.

We do not find that Mr. Watt has ever erected a continuous circular engine: he has doubtless found all his attempts inferior to the reciprocating engine with a fly. A very crude scheme of this kind may be seen in the Transactions of the Royal Society of Dublin, 1787.

Mr. Cartwright, in a patent of 1797, proposes some improvement of Mr. Watt's rotative engine, but it was never brought into use. Mr. Jonathan Hornblower had a patent in 1798 for a rotative engine, which is the most ingenious of all the speculations on this subject, but too complicated to be carried into execution; and in 1805 he had another patent, for a machine which is quite different from the former, and is ingenious, but still less likely than the first to answer the intended purpose.

Mr. Samuel Clegg has made a rotative engine, the piston of which makes a complete revolution in a channel at a distance from the centre of motion. We have seen this engine at work, which acted in a very regular manner, but we think the friction must be greater than that of a common engine, although it gets rid of the reciprocation. Mr. Clegg had a patent in 1809 for his invention.

Mr. Turner has lately obtained a patent for a rotatory steam-engine, the principle of which is the same as Mr. Clegg's, but each of them has its peculiar advantages in the manner of fitting up, and in the arrangements of its parts. Mr. Turner's is packed in all the moving parts with metallic packings instead of hemp, and we have been informed that his engines operate very well, and without any fly-wheel. Mr. Clegg's engine only requires a small fly at one part of its movement. We think, that if ever rotative engines are brought to perfection, it will be by something of the nature of these two engines, which are the most practicable, and promise greater probability of success than any before invented.

For the application to steam-boats, and to the purpose of drawing carriages, or locomotive engines, as they are now called, rotative engines would be so advantageous, that they

would be very useful, even though they should consume rather more fuel than reciprocating engines of the same power, provided they were certain in their action.

Cement for making Joints in Steam-Engines.—In joining the flanches of iron cylinders, and other parts of hydraulic and steam-engines, a strong and durable cement is required. The following are receipts for cements proper for such purposes. Mix boiled linseed oil, litharge, red and white lead, together to a proper consistence: this cement is to be applied on each side of a piece of flannel, previously shaped to fit the joint, and then interposed between the flanches, before they are brought home to their place by the screws or other fastenings employed, which will make a close and durable joint. The quantities of the ingredients may be varied without inconvenience, only taking care not to make the mass too thin with the oil. It is difficult, in some cases, to make a good fitting of large pieces of iron work at once, and this renders it necessary sometimes to join and separate the pieces repeatedly, before a proper adjustment is obtained. When this is expected, the white lead ought to predominate in the mixture, as it dries much slower than the red. A workman knowing this fact, can exercise his own discretion in regulating the quantities; but it is safest to have too much rather than too little white lead, as the durability of the cement is no way injured thereby, only a longer time is required for it to dry and harden. When the fitting will not admit of so thick a substance as flannel being interposed, linen may be substituted, or even paper or thin pasteboard, the only reason for employing any thing of the kind being the convenience of handling. This cement answers well also for joining broken stones, however large. Cisterns built of square stones put together with this cement, will never leak or want any repairs: in this case the stones need not be entirely bedded in it, for an inch or even less of the edges that are to lie next the water need only be so treated, and the rest of the joints may be filled with good lime.

Another cement, which is preferable to the former for withstanding the action of steam, is compounded as follows: Take two ounces of sal ammoniac, one ounce of flour of sulphur, and 16 ounces of cast-iron filings or borings: mix all well together by rubbing them in a mortar, and keep the powder dry. When the cement is wanted for use, take one part of the above powder, and 20 parts of clean iron borings, or filings, and blend them intimately by grinding them in a mortar: wet the compound with water, and when brought to a convenient consistence, apply it to the joints with a wooden or blunt iron spatula.—By considering the affinities of these ingredients, those who are at all acquainted with chemistry, will be at no loss to comprehend, that a degree of action and re-action takes place among the ingredients, and between them and the iron surfaces, which at last causes the whole to unite as one mass: in fact, after a time, the mixture and the surfaces of the flanches become a species of pyrites, holding a very large portion of iron, all the parts of which cohere strongly together. Another cement of the same kind is made by mixing together two parts of flour of sulphur, and one part of sal ammoniac, and making them into a stiff paste with a little water. When the cement is wanted for use, dissolve a portion of the above paste in urine, or in water rendered slightly acidulous; and to this solution add a quantity of turnings or borings sifted, to get rid of the grosser particles. This mixture, spread upon or between the flanches of iron pipes, or put into the interstices of other parts of iron work, will in a little time become as hard as stone.

Mr. Murray's Rule for the Weight of Fly-Wheels to Steam-Engines.—Mr. Buchanan, in his valuable treatise on propelling vessels, printed at Glasgow in 1816, gives the fol-

lowing rule, as the result of Mr. Murray's long experience in building engines.

Rule.—Multiply the number of horse-power of the engine by 2000, and divide it by the square of the intended velocity of the circumference of the fly-wheel in feet per second, the quotient will be the weight of the fly-wheel in hundred weights.

Example.—To find the weight of a fly-wheel proper for an engine of 20 horses' power, supposing the fly-wheel to be 18 feet in diameter, and to make 22 revolutions per second: wheel 18 feet diameter 56 feet circumference \times 22 revolutions per minute = 1232 feet motion per minute \div 60 = $20\frac{1}{2}$ feet motion per second for the motion of the circumference of the fly wheel. Then $20\frac{1}{2}$ feet per minute squared = $420\frac{1}{4}$, and 20 horses' power \times 2000 = 40000 \div $420\frac{1}{4}$ = 90.4 cwt. of the wheel required.

Smoke-Burning Furnaces for Steam-Engines.—The great quantity of smoke which is thrown out by the furnaces of steam-engines, becomes a great annoyance in a town such as Manchester or Birmingham, where there are many engines together. To avoid this, as well as from an idea of obtaining a greater effect from the combustion of the smoke, many inventors have been induced to contrive furnaces which shall not produce any smoke. The black smoke which is usually discharged at the top of the chimney, is, in fact, so much good fuel, which only wanted a sufficient heat, and the contact of fresh air, to inflame it under the boiler. It is a fact well known, that the flame which is often seen issuing from the top of the chimneys of founderies, furnaces, &c. has no existence except at the top of the chimney; for while it is ascending the flue, it is only dense, black smoke, consisting of the azote of the atmospheric air which has passed through the fire, of hydrogen gas, coal-tar, and carbonaceous matter; and this smoke is of such a high temperature, that it only requires oxygen to make it inflame instantaneously: this it obtains from the atmospheric air, into which it descends on issuing from the top of the chimney, and then presents such appearances, as would make a hasty observer adopt the opinion that the flame had ascended, in the state of flame, from the fuel in the furnace, through the whole height of the flue, up to the top of the chimney; but this is by no means the case, and a consideration of this simple fact will convince any person, that it is not an inconsiderable proportion of the fuel that is thus wasted. Nor is this the only loss sustained; a quantity of heat is required, not merely to render such a portion of the fuel volatile, but to give it a temperature sufficient to produce the spontaneous inflammation at the top of the chimney, of which we have taken notice. This must be furnished at the expence of an extra and unnecessary quantity of fuel.

The first of the smoke-burning furnaces was Mr. Watt's patent of 1785. His method consists in causing the smoke, or flame, of the fresh fuel, while passing from the fire to the flue or chimney, to pass, together with a current of fresh air, through or among fuel which has already ceased to smoke, or which is converted into coke, charcoal, or cinders, and which is intensely hot; by which means the smoke, and grosser parts of the flame, by coming in close contact with the intensely hot fuel, and by being mixed with the current of fresh or unburnt air, will be consumed or converted into heat, or into pure flame, free from smoke. This invention is put in practice, first, by stopping up every avenue or passage to the chimney or flues, except such as are left in the interstices of that part of the fuel which is ignited; secondly, by placing the fresh fuel above, or nearer to the external air, than that which is burning, and already converted into coke or charcoal; thirdly, by constructing the fire-place in such

manner, that the fresh atmospheric air which animates the fire, and the smoke or flame which rises from the fresh fuel at the first application of the heat, must pass downwards, or laterally, so as to pass through the whole mass of burning fuel, and issue from the interstices of the burning fuel at the most remote part, or internal end of the fire-place, to escape into the flues or chimney. In some cases, after the flame has passed through the burning fuel, it is made to pass up a very hot funnel, flue, or oven, before it comes to the bottom of the boiler, by which means the smoke is still more effectually consumed.

This invention of Mr. Watt's has been very extensively practised; but another plan, by Mr. Robertson of Glasgow, has since been found preferable: it is nearly on the same principle as Mr. Watt's. The opening through which the fuel is introduced into the furnace is shaped like a hopper, and is made of cast-iron, built into the brick-work of the furnace. From the mouth, or entrance of the hopper, it inclines downward to the place where the fire rests on the bottom grate.

The coals in the mouth-piece, or hopper, answer the purpose of a fire-door; and the principal point to be attended to in the management of this furnace is, that the hopper shall be kept full of coal, either wholly or in part with small coal, to prevent as much as possible the air entering by that passage. The coals which are in the lowest end of the hopper are brought to a state of ignition by the heat of the fire upon the bars, before they are forced upon the bars to be burned.

Beneath the lower part of the hopper the furnace is provided with front bars, which serve to admit air among the fuel which lies upon the grate, and offer a ready mode of forcing the ignited fuel, which has just issued from the lower part of the hopper, back upon the fire-grate, where it is completely consumed, and by thus forcing it back, a space is made, into which fresh fuel falls from the lower part of the hopper; but all the smoke which rises from this fresh fuel must pass through the burning fuel, which lies upon the farther part of the grate, and is thus consumed. By this arrangement, the fuel is brought into a state of ignition before it reaches the farther side of the bottom grate, where it is stopped by a rising breast of brick-work; therefore, any smoke which is liberated from the raw coals in the mouth-piece, must pass over these burning coals before it can reach the flue of the chimney; but this, though it would cause a large quantity of the smoke to be burnt, would not completely prevent the escape and ascent of smoke up the chimney; for it is not sufficient that the smoke should be exposed to a heat sufficient to ignite it before it escapes; as, unless a quantity of fresh air, able to furnish a sufficiency of oxygen for the combustion of the smoke, can be brought at the same time in contact with it, it will still escape in an undecomposed state.

The principal merit of Mr. Robertson's invention consists in a judicious admission of fresh air, in such a manner that it can reach the smoke without previously passing through the fire, and parting with its oxygen in its passage, and that it shall be in such quantity, as merely to cause the smoke to burn, and not to cool the bottom of the boiler. Beneath the upper side of the mouth-piece, or hopper, which incloses the fresh fuel, and at the distance of about three-fourths of an inch from it, (this space being a little more or less, according to the size of the furnace,) is placed a cast-iron plate, which is above the hopper containing the fuel; and in the space between it and the top of the hopper is an open space for the admission of a thin stream of air, which, rushing down through the opening, comes first in contact

with that part of the fire which is giving out the greatest part of the smoke; viz. the fuel that has been last introduced from the lower end of the hopper upon the grate-bars, mixes with the smoke before it passes over the burning fuel upon the interior part of the grate-bars, where it is in a high state of combustion: this enables the smoke to inflame completely. The quantity of air thus admitted to pass over the upper surface of the fuel newly introduced, is a matter of importance to the complete action of the contrivance. The opening for air is regulated by a very simple contrivance. The plate which forms the upper side of the opening for the passage of the air, rests at each end on a stud, or pin, projecting from the cheeks of the mouth-piece, or it is furnished at each end with a pivot, which works in the cheeks. These pins, or pivots, being placed about half-way between the outside and inside of the mouth-piece, or hopper, by elevating or depressing the outer edge of the plate, the opening for the admission of air between the lower end of the hopper and the lower edge of this plate can be diminished or enlarged. When that degree of opening which produces the best effects is obtained, which is easily known by experiment, the plate is kept in its place by means of a piece of iron introduced above it, and answering the purpose of a wedge. These furnaces have been adopted by many manufacturers at Leeds, Manchester, and in London, where many works have been indicted as a nuisance for not having adopted the improvement; the magistrates arguing, that though the welfare of the place required that such inconveniences should be submitted to while no possible remedy for them was known, the health and comfort of the inhabitants equally demand, now that evil can be done away, that smoking furnaces should not be permitted in the place. On this account, Mr. Robertson's furnaces have been very much adopted; but we have seldom seen them in such order as to make any diminution in the smoke, which they will do completely, if the regulation of the quantity of air is properly made.

A recent invention by Mr. John Cutler in 1815, is found to burn the smoke most perfectly in common fire-grates, such as are used for warming apartments; and we have seen an experiment of this plan upon a small engine boiler, which seemed to promise great success in applying it on a larger scale; but such trials have not yet been made, nor the best form of the apparatus settled.

Mr. Cutler's invention consists in applying beneath the place in which the fire is to burn, a chamber or magazine, which is made as close as can be on all sides, except the top, and is of sufficient capacity to contain within it a magazine of fuel, sufficient to supply the combustion for a whole day, or other required space of time. The fire is made upon the top of the mass of fuel which is contained in the magazine, and there are no grate-bars upon which the fire is to lay; but instead, the bars are placed at the side, in a sloping direction, so as to inclose the fire in a grating, which will admit sufficient air sideways to supply the combustion. The bottom of the magazine is made moveable up and down in the chamber; and by means of a rack and pinion, a screw, or some other mechanical power, the whole weight of coals contained in the chamber can be raised up, and a portion will rise up into the grated part, where air is supplied to it, so that it can burn; for the principle of this invention is to make the magazine-chamber beneath so close as to exclude the air from it, so that the fire cannot burn the fuel contained in it, and to provide that part of the fire-place which is immediately above the top of the chamber with a plentiful supply of air to burn the fuel. By means of the machinery, any

quantity of fuel can be raised up out of the magazine-chamber to supply the deficiency occasioned by the combustion.

The manner in which it burns the smoke, is by obliging it to pass through the burning fuel which lies upon the top of the mass of coal contained in the magazine, because this burning fuel communicates sufficient heat downwards to make the smoke rise from the fuel, and this smoke must pass through the fire above it; but before the fuel comes to be actually burned, the smoke is so far extracted, that the coal is in the state of coke.

The machinery by which the bottom plate of the magazine and the fuel contained in it is raised up, is simply an axle, with chains winding upon it; at least that is the contrivance which Mr. Cutler used in the small stoves for warming apartments; but what method will be found best on a large scale, for its application to steam-engines, remains yet to be determined. We shall give a more minute description of this valuable invention under the article *STOVE*.

The Application of the Steam-Engine to propel Boats or Ships.—This is one of the most valuable applications of the power of steam, next to that of draining mines; and though proposed at a very early period, has been but lately brought into use.

Captain Savery, in 1702, mentions the application of his engine to a ship, but gives no account of the manner of carrying it into execution; probably he only intended it for pumping out leakage-water.

Mr. Jonathan Hull's patent of 1736, for carrying vessels or ships into or out of any harbour, port, or river, against wind or tide, or in a calm, is the first idea of applying the steam-engine to the purpose of propelling vessels. The engine of Newcomen was made to actuate a wheel placed in a frame projecting from the head of the boat, and the oars or paddles of the wheel were to strike in the water, and advance the boat or vessel containing the engine, which would draw after it the ship or vessel that was to be rowed into or out of the harbour. We have no account of any actual trials made by Mr. Hull; but besides his patent, we have a small pamphlet, printed in 1737, with an engraving.

The account which Mr. Buchanan gives of the introduction of steam-boats in his treatise on propelling vessels, is, that Mr. Miller of Dalswinton, who made many models and experiments with a view to the improvement of naval architecture, appears to have made the first attempt at working a vessel with steam. The vessel was double, with the paddle-wheels in the middle: the experiment, however, did not succeed to his satisfaction.

About the year 1795, Lord Stanhope constructed a vessel, which was tried in Greenland dock: the paddles were made in the imitation of the feet of a duck, and were placed under the quarters of the vessel, but the mechanism did not answer his lordship's expectation.

In the year 1801, Mr. Symington tried a vessel propelled by steam on the Forth and Clyde Inland Navigation, but it was laid aside, on account of the injury which it threatened to the banks of the canal, by the surge of water which it made. It does not appear that he tried this vessel on any river.

Mr. Symington's steam-boat is slightly described in the Journals of the Royal Institution for 1803, from which it appears, that the method employed by him for making the connection between the piston and the water or rowing wheel, was by placing the cylinder nearly in a horizontal position. This is attended with several advantages: the necessity for a beam is avoided, which has ever been a troublesome and expensive part of the common engine. The piston is sup-

ported in its position by friction-wheels, and communicates, by means of a rod, with a crank connected with a wheel, which gives a motion to the rowing-wheel somewhat slower than its own; the water-wheel serving at the same time as an addition to the fly. The steam-engine differs but little in its action from that improved by Mr. Watt; there is, however, an apparatus for opening and shutting the cock at pleasure, in order to reverse the motion of the wheels, and put the boat back whenever it may be necessary. The water-wheel is situated near the stern, and in the middle of the breadth of the boat, so that it becomes necessary to have two rudders, connected together by rods, which are moved by a winch near the head of the boat: by this means the person who attends the engine is able to steer also.

Another part of Mr. Symington's invention consisted in the application of stampers at the head of the boat, for the purpose of breaking the ice on canals: these were to be raised in succession by means of levers, the ends of which were depressed by the pins of wheels, turned by an axis communicating with the water-wheel. Mr. Symington stated, in a calculation he made, that a boat doing the work of twelve horses, could be built for eight or nine hundred pounds; and he had ascertained by experiment, that it would travel at the rate of two miles and a half *per* hour. This is a very slow motion, compared with the present steam-boats, as we shall see.

In 1807, Mr. Fulton of New York introduced steam-boats into America, which were the first that succeeded in a large way, so as to become profitable: they had before this been used in America, and were begun there by Mr. Symington. In 1812, a large boat was set to work on the Clyde, in Scotland; and since that time, great numbers have been made both in Scotland and in different parts of England.

There are several different methods of applying the force of machinery to row boats: the most obvious is by means of oars, similar to those with which a boatman rows; but this action is very difficult to imitate by machinery, and has never been brought into practice. Several ingenious schemes may be found in the *Machines Approuvées par l'Académie*.

The next is by means of paddle-wheels, which are similar to an undershot water-wheel; and when turned rapidly round by the engine, the floats dip into the water, and row the boat along. This plan was first put in practice by the ingenious captain Savery, in 1702; but to be turned by men working at a capitan instead of a steam-engine, is now adopted in all the real working steam-boats which have been made. Two wheels are usually placed at the sides of the boat, at about one-third of the length from the head. Attempts have been made to place one wheel in the middle of the boat, but they have not succeeded so well as the others.

Another method is by forcing a stream of water out at the stern of a boat by a large pump, which at the same time draws the water in at the head of the boat. This was suggested by Dr. Franklin, after M. Bernoulli, and was very effectually tried by the late Mr. James Linaker, master millwright of the dock-yard at Portsmouth, but found inferior to the paddle-wheels. It has been also proposed to force out air under the stern of the vessel by a pump, but we do not think it likely to succeed.

A fifth method is by a screw applied at the stern of the vessel, and turned round by the engine.

Lastly, various forms of oars have been applied at the stern of the vessel to move from side to side, and impel the vessel on the same principle, as what seamen call skulling a boat, by an oar at the stern.

As none of these schemes, except the paddle-wheels at the outfides of the boat, have been brought to any practical utility, we shall not enter into any further particulars, but describe one of the best of these vessels, such as is employed on the Clyde at Glasgow, where steam-boats have been brought to the greatest perfection.

All these vessels are upon one general plan, viz. that of having paddle-wheels, similar to under-shot water-mill wheels, on each side of the boat, which are put in motion by the steam-engine. In some of these wheels the paddles are placed parallel to the axis of the wheel, in others they are placed obliquely, and in others again they are curved; and it is not yet ascertained which is the best form; for although some boats are found to move with a much greater velocity than others, it is difficult, where so many causes are combined in the operation, to ascertain which one singly produces the advantageous effect. Experiments are yet wanting to ascertain the best number for the paddles on the wheel, and with what velocity they should move. It would doubtless be of advantage to have the means of changing the velocity of the paddle-wheels, according to the circumstances of the current of the water in which the boat moves; because when the boat is moving with the current, the paddle strikes against the water in a contrary direction to its motion, and therefore has the greatest force to urge the boat forwards, at the same time that the boat is moving in the direction of the current, and therefore moves more easily. On the other hand, suppose the boat moving against the current, the paddles must row the water in the direction of the current, so that supposing they move only with the same velocity, they must have much less force to advance the boat, at the same time that the boat, having to oppose the current, requires a greater force to propel it. One of the steam-boats on the Clyde has eight paddles to each wheel, but it is probable seven would be more effective; because it is evident, that if too many paddles are used, the water will be so much broken, that it cannot afford that resistance to the motion of the paddle which alone causes the boat to advance. For an extreme case, suppose so great a number of paddles that they would nearly touch, the wheel would then resemble a solid cylinder, and have no effect to propel the vessel. The velocity with which the paddle strikes the water must be considerable, to obtain a great resistance from the water; but the stroke must not be too frequently repeated, or the water which the paddle removes will not have time to return to its level before the succeeding paddle makes its stroke.

The steam-engine is placed near the middle of the vessel, and the smoke is carried up in a large plate iron tube, which serves the purpose of a mast, to hoist a sail when the wind favours. The greatest number of boats at present in use are fitted up for passage-boats, as that is the most profitable employment: they have two cabins, one before the engine, which is smaller, and considered inferior, while the second, or large cabin, abaft the engine, is more elegantly fitted up. *Plate VIII. Steam-Engine, fig. 1.* is an elevation of the whole vessel, as she appears in the water, and *fig. 2.* a plan with the deck removed, to shew the arrangement of the apartments, and to explain the steam-engine and machinery by which the vessel is propelled.

That part of the boat which is beneath water, is built like an ordinary boat, which draws but little water, and she is so formed at the stern-parts as to cause her to steer readily. The head must be built more bold or rounding for those boats which are intended for the sea, than those for rivers, which are generally made very sharp at the head, so as to divide and move more freely through the water. The rudder and tiller are constructed the same as other boats. The width of the vessel above water is considerably increased, by

the addition of galleries or gangways, X, X, which are fixed projecting from her sides and gunwale: they are composed of a thin planking, and are supported by knees and stanchions, so as to form a gangway to walk round, and at the same time a defence to the paddle-wheels B, B, which are placed close to the sides of the vessel in the width of the gangways. These wheels are put in motion by the steam-engine, and by their action against the water propel the boat forward. The paddle-wheels are constructed nearly in the same manner as under-shot water-wheels, except that the floats or paddles are placed inclined to the axis, instead of being perpendicular to the plane of the rim of the wheel. The upper parts of the wheels are inclosed in semi-circular cases of thin boarding Y (*fig. 1.*), to prevent the action of the wind upon their floats, which, without this precaution, would materially impede their motion, because the floats at the upper part of the wheels move in a contrary direction to those at the lower part, where they dip into the water.

The steam-engine which gives motion to the wheels, is situated in the middle of the boat; but it must be placed low, and, if possible, beneath the water-line, so as to act in part as ballast to the boat, which will otherwise require a greater quantity of ballast than usual to counteract the weight of the engine. It is a great advantage to these boats to be light, and draw little water; these engines must therefore be made as light and compact as is possible, that none of the parts shall break. The principal parts which require strength should be made of good wrought iron, in preference to cast iron, which is used for other engines; for instance, the beam and connecting rods, and also the cranks and shaft for the fly-wheel, as well as those for the paddle-wheels. The wheels themselves are made of thick iron plate or wood; the boiler A (*fig. 2.*), in which the steam is produced, is made of strong wrought-iron plates, and as large as the space which can be allowed for it will admit, that it may produce a regular supply of steam to the engine: it is placed sometimes across the vessel, and sometimes in the direction of its length, as shewn in the figure; and the fire-place is an iron tube contained within: *d* is the fire-door: the smoke, after passing through two or three turns of the tube in the boiler, passes off through the chimney C, which is an iron tube, erected perpendicularly in the centre of the vessel, to a considerable height, as shewn in the elevation, and is stayed, in the same manner as a mast, by two ropes, or sometimes by iron chains from its top, going fore and aft, with a purchase to each to draw them always tight. There is a safety-valve at *e*, by which the steam escapes into the chimney when it is produced in too great a quantity, and becomes too strong, or when the engine is not in motion: *e* is the steam-pipe, which conveys the steam from the boiler to the steam-box *f*, which contains the four valves for distributing the steam into the cylinder G, alternately above and below the piston, so as to give motion to the engine. These valves are made to work on the plan of Mr. Murray's patent, with the spindle of one through the other. The top of the piston-rod is jointed to the middle of a cross-rod, from the ends of which the two iron rods descend, one on each side of the cylinder, and are jointed to the beam, G P, which is made double, or composed of two levers, joined together in the manner of a frame, so that the cast-iron condensing cistern of the engine is contained between the two, as they work up and down: the beam-centre, or axis of motion, is supported by two bearings screwed up to the bottom of this cistern, so that the beams lie close to each side of the cistern: the cylinder is screwed down upon one end of the condensing cistern, and the bearings for the axis of the crank, R, are supported on the other end. The beams, G P, are united together at the extremity most remote from the cylinder by a cross rod, on

the middle of which the connecting rod is jointed, which rises upwards to the crank R, on the shaft or axis of the fly-wheel M: this crank-axis is supported in bearings close on each side of the crank, which are framed to the condensing cistern, and also two others at the extremities of the axis, which are placed on the gunwale of the boat, so that the shaft extends completely across the vessel, passing through the boiler A, in a tube which extends across it, as shewn by dotted lines at *a*. On each end of the crank-shaft two cog-wheels are fixed, engaging in the teeth of two other wheels, O, O, fixed upon the shafts of the paddle-wheels B, B. These last-mentioned shafts are each supported in two bearings, one on the outside beam of the gangways or platforms, and the other on the gunwale of the vessel: the cog-wheels, O, O, are fixed on the extreme ends of the shafts within the vessel, and they are one-third or one-fourth larger than the wheels on the axis of the crank, so that the paddles do not turn so fast as the fly-wheel of the engine.

It is needless to enter into a description of the action of the steam-engine: the construction of the valves is the same as described in a former part of this article (*Plate VII. fig. 5.*), and the engine acts the same as Mr. Watt's double-acting engines; but it is necessarily modified, to suit its particular situation, which occasions some defects. The cylinder must be made very short, to come into the height of the boat; and the connecting rod is so short, that the obliquity of its action on the crank is very great. The air-pump, H, is worked by a cross-rod, which moves up and down with the beams, being connected to them by perpendicular rods. The requisite movement is communicated to the valves of the engine by the rod *ip*, one end of which has a circular hoop, that embraces an excentric wheel *p*, fixed on the axis of the fly-wheel; so that in turning round, it pushes the rod *ip* backwards and forwards, in the manner of a crank, and thereby alternately opens and shuts the valves at the proper instant to produce the motion. There is a throttle-valve placed in the steam-pipe at *e*, for regulating the velocity, or stopping the engine, when required.

The arrangement of the apartments in a steam-vessel may be varied according to the purpose for which she is to be employed. In the drawing, we have given the arrangement which appears best adapted for the convenience of passengers, in a vessel for quick travelling. (See the plan, *fig. 2*.) The after or grand cabin, marked 1 in the figure, is generally fitted up and furnished in an elegant style, for the use of the best company, who also occupy the deck and gangways about the chimney. The entry to the grand cabin is at the stern of the vessel. The grand cabin is generally situated in the after-part, on account of there being the most room in that part, the engine being always placed considerably nearer the head of the vessel than the stern: 3 is a small room for the use of the passengers, and has a door coming out on the gangways. The entry to the engine-house is by steps from the gangway on the opposite side; and the same entry serves for a small room 4, in which the steward keeps his stores. The coals for working the engine are stowed beneath the floors of the cabins, and the engine-man draws them out with a long hook as he wants them. The forward-cabin, 5, is for passengers who pay less than the others: it has a large counter or chest in the middle, which will contain all the luggage, and serves also as a table for those who sit round it. These passengers have the use of the deck forwards of the chimney; but the gangways at that part are almost entirely occupied by a large water-cask on each side, the cable, spare sails, or whatever the vessel may require. The rigging of the boat

is evident from *fig. 1*: she carries two large lugger-sails, one fore and the other aft; but as these are only intended to be used in fine weather, with a fair and light wind, the masts and cordage may be as light as is convenient. A pair of haliards should be provided to the chimney, to hoist occasionally a large light lugger-sail; and if the chimney is not sufficiently strong, a pair of extra stays may be set up to strengthen it. The chimney is generally made to lower down, for the convenience of passing bridges, when the vessel navigates a river.

The paddle-wheels of one of the boats on the Clyde, which, Mr. Buchanan says, is considered as a standard, are 8 feet 10 inches diameter, and 4 feet wide, and are calculated, when the engine makes 45 strokes *per* minute, to move at the circumference, or strike the water at the rate of 13 miles *per* hour. She is about 80 tons burden, and is 69 feet from stem to stern, and 15 feet 2 inches wide in the beam. The engine is of 14 horses' power, and she goes at an average six miles *per* hour in still water: therefore, if there is a current, she will go as much faster or slower than six miles *per* hour as the velocity of the current. The motion of the paddles is rather more than twice that of the boat.

Steam-boats have been built with much more powerful engines, even 20, 25, and 30-horse power; but the increase of the velocity has not been in proportion to the increase of the power of the steam-engines. This will not be surprising, when it is considered that the resistance to which a boat is subject, increases not in an arithmetical proportion, (as 1, 2, 3, 4, 5, &c.) but in proportion to the squares of velocity (as 1. 2. 4. 8. 16. 32.) In other words, to make the same vessel move with ten times a given velocity, it requires one hundred times the power; and it is farther to be considered, that one or more powerful engines above mentioned are heavier, and require a greater floating body to support them, which of course increases the resistance. On railways, an increase of velocity requires only an arithmetical increase of power; and to draw a carriage on a railway with ten times a given velocity, would require only ten times the given power.

Steam-boats require a greater power of steerage than any other vessel of their size, as those hitherto constructed are less easily turned than vessels impelled by sails only. The tendency of the wheels acting so near the centre line of the vessel, is to propel her straight forward; whereas in turning a sailing vessel to the wind, the sails aid her in coming about; and even common oars act so far out from the side of the vessel, that they have much more power to bring her round than the wheels of a steam-boat can possibly have.

A most important point is to have a good steam-engine. All the engines hitherto used in Scotland have been made on Mr. Watt's principle; but those in America have been high-pressure engines, which being more simple, and less expensive, some have been constructed in England. But one of them having exploded in an American boat, the proprietors of some of the English boats have changed their engines for others on Mr. Watt's principle, to avoid similar accidents. We think it quite unjustifiable in any engineer to advise the construction of steam-boats with high-pressure engines, at least for passage-boats, in which so many persons are always assembled together, and so near to the engine, that they would be all destroyed in the event of the boiler bursting.

Those engines which work with a bell-crank, or a double beam, below the cylinder, and on each side the cistern, instead of a beam working above, are found to strain the vessels: those having the beam above, work much more

Readily. The engines that Messrs. Boulton and Watt have hitherto constructed have had beams: other engines have had cylinders horizontally. Mr. Brunel's engine, of which we have before spoken, has two cylinders acting alternately, so as to require no fly-wheel; but many engines, on the common construction, have been made without fly-wheels, by having the paddle-wheels sufficiently heavy to answer the purpose.

With regard to fuel, it is obviously much more difficult to have every thing kept in proper order in a boat, where the engines are much confined, and the cylinder is made to work with very short strokes, by which the action on the crank is so oblique, and changes its direction so frequently, that the greater part of the power is lost. The quantity of fuel constantly used in steam-boats has been much greater than the usual allowance for Messrs. Boulton, Watt, and Co.'s steam-engines. For one of 14-horse power, they allow 1 cwt. 1 qr. 20 lbs. *per* hour of good Newcastle coal; but Glasgow coal is much weaker. One of the boats, with an engine of 33 horse power, requires 3 tons 12 cwt. from Glasgow to Greenock (fully 29 miles), and back to Glasgow. One of 15-horse power, and another of 8-horse power, take each the same quantity, *viz.* from Glasgow to Greenock (26 miles), and back to Glasgow, 1 ton 1 cwt. For farther particulars on steam-boats, see Robertson's *Essay on Propelling Vessels*, 8vo. 1816.

The Application of Steam-Engines to driving of Carriages.—These are now called locomotive engines, and we may date their introduction with the patent of Messrs. Trevethick and Vivian in 1802, for the high-pressure engines, which were expressly intended for working carriages. It would have been very difficult to have succeeded with any other kind of engine, as the weight of the water necessary to effect condensation must be so great. Mr. Trevethick made a locomotive engine in South Wales in 1804, which was tried upon the rail-roads at Merthyr Tydvil. The engine was the same as that of which we have given an account of its work in speaking of the high-pressure engines, having an eight-inch cylinder, and a four-feet six-inch stroke. It drew after it, upon the rail-road, as many carriages as carried ten tons of bar-iron, for a distance of nine miles; and it performed all that distance without any farther supply of water than that contained in the boiler at setting out, travelling at the rate of five miles *per* hour.

Since that period they have been tried in many places upon rail-roads, but we do not think they had been really put in practice, so as to work constantly, until 1811, when Mr. Blinkinop, proprietor of the Middleton coal-works, which supply the town of Leeds, adopted them for conveying the coals on his rail-road.

Mr. Trevethick's first engines consisted of a high-pressure engine, with a boiler of cast-iron, of a cylindrical form, six feet long, and four feet three inches diameter, the fire-place being within. The cylindrical boiler was mounted horizontally upon four wheels, and the cylinder of the engine was placed vertically in the end of the boiler, having two connecting rods descending from the cross-bar of its piston-rod to two cranks, upon an axis extending beneath the boiler and cylinder, and communicating its motion, by means of wheel-work, to the two fore-wheels, upon which the engine runs; and by this means the alternate ascending and descending motions of the piston-rods act to turn round the crank and wheels, and draw the carriage forwards: in this way no fly-wheel was necessary, because the momentum of the carriage to advance itself forwards on the road, continued the motion of the wheels and cranks sufficiently to make the cranks pass the lines of the centre. Where these engines were tried, it was found diffi-

cult to make the wheels take sufficient hold upon the railway to draw any considerable load after it, unless the weight of the engine and work resting upon the wheels was made very considerable, and then the common iron-rails of the railway were sometimes broken by the passing of the engine.

Mr. Blinkinop, when he adopted the locomotive engine, took up the common rails on one side of the whole length of the road, and replaced them with rails which had large and coarse cogs projecting from the outside. These cogs are cast at the same time with the rails, and are hollow beneath, to be as light as is consistent with strength and durability. The pitch of the cogs, or distance from centre to centre, is six inches, so that each rail, of three feet in length, has only six cogs. A wheel, which is fixed on an axis at one side of the carriage, works in the teeth of the rails; and as it is turned by wheelwork from the axis of the cranks, the whole machine is caused to advance along the railway. When we saw Mr. Blinkinop's first trial, he employed a small condensing engine, but finding the water to grow so hot that he gained but little by the condensation, he applied a high-pressure engine with a wrought-iron boiler, and two cylinders in it acting upon separate cranks, so as to produce a constant action to advance the carriage without the necessity of using a fly-wheel.

A similar machine has been tried at Newcastle, but they have attempted to employ the wheels alone, without cogs upon the rails. To relieve the weight upon the rails, and obtain greater re-action to advance the carriage, they applied six wheels for the carriage to run upon; and to make the bearing equal upon all six, the two middle wheels were applied to the piston of a small cylinder beneath the carriage, into which steam was admitted, and by its pressure bore up a portion of the weight of the engine; and accommodated itself to any inequalities of the railway.

At present, locomotive engines have been confined to moving upon iron-railways: to make steam-engines draw carriages upon public roads, is a refinement not yet attained.

In drawing up this article, we have derived considerable assistance from books, as our numerous references will testify; at the same time we cannot refer to any one work in the English language for a more detailed account of the steam-engine than we have here given. Many detached memoirs on particular points of the principle or construction of the steam-engine, may be found dispersed through the forty-six volumes of the *Philosophical Magazine*, and the *Philosophical Journal*. The first and second volumes of the quarto series of the latter work contain a sketch of the history of the invention, but no particulars which are not given more at large in this article.

The *Repertory of Arts, Manufactures, and Agriculture*, consisting of sixteen volumes of the first series, and twenty-eight volumes, now published, of the second series, contains the specifications of a great number of patents for inventions relating to the improvement of steam-engines, of which we have noticed nearly all in this article, which appeared to possess merit, or to have been successfully put in practice.

The article *Steam-Engine* in the third edition of the *Encyclopædia*, which was written by Dr. Robison, is the best and most philosophical view of the subject, but he has not entered at all into details: and as this was composed twenty years ago, the improvements made since that period, in the construction of the machine, have made a total change.

The fullest account of the improved steam-engine is by the celebrated French engineer, M. Prony, who devotes the second volume of his "*Nouvelle Architecture Hydraulique*," 1796,

expressly to that subject. He describes four or five engines, with a great number of large plates, containing every detail of their construction. The work is little more than a description of the plates. These engines are not the best specimens of Mr. Watt's invention; they were all constructed in France by M. Perrier of Paris, who, in 1780, erected a large engine at Chaillot, to pump up the water of the Seine for the supply of the town, and another of smaller dimensions on the opposite side of the river at Gros Caillou. These engines are still at work, and the writer of this article visited them in 1814; they are upon the plan of Mr. Watt's first engines, though, for want of attention to some minute particulars, they do not produce any great effects. M. Perrier had visited England to obtain the requisite instructions for making these engines.

The double-acting engine of Mr. Watt was carried into France by M. Betancourt, whose experiments on the expansive force of steam are referred to in this article. This gentleman came to London in 1788, with a view of collecting models of improved hydraulic machines for the court of Spain, and was admitted to examine the steam-engines made by Messrs. Boulton and Watt at the Albion Mills for grinding corn, which were the first large double-acting engines they had made. M. Betancourt has, in effect, made a kind of secondary claim to the invention of the double engine; for he informs us, that he saw in part the exterior construction and operation of those machines, but the interior mechanism was so concealed from him, as well as from others who had had the same curiosity before him, that he could only guess at the nature of the construction. He observed, that the chains which are usually applied to the extremities of the beam were suppressed, and that, instead of these, they had applied the parallel motion; that the different parts of the machine were so masked by the distribution of the building, which isolated even the exterior parts into different apartments, as to prevent him from comprehending their correspondence; but, from the result of all his observations, he concluded the machine was of double effect.

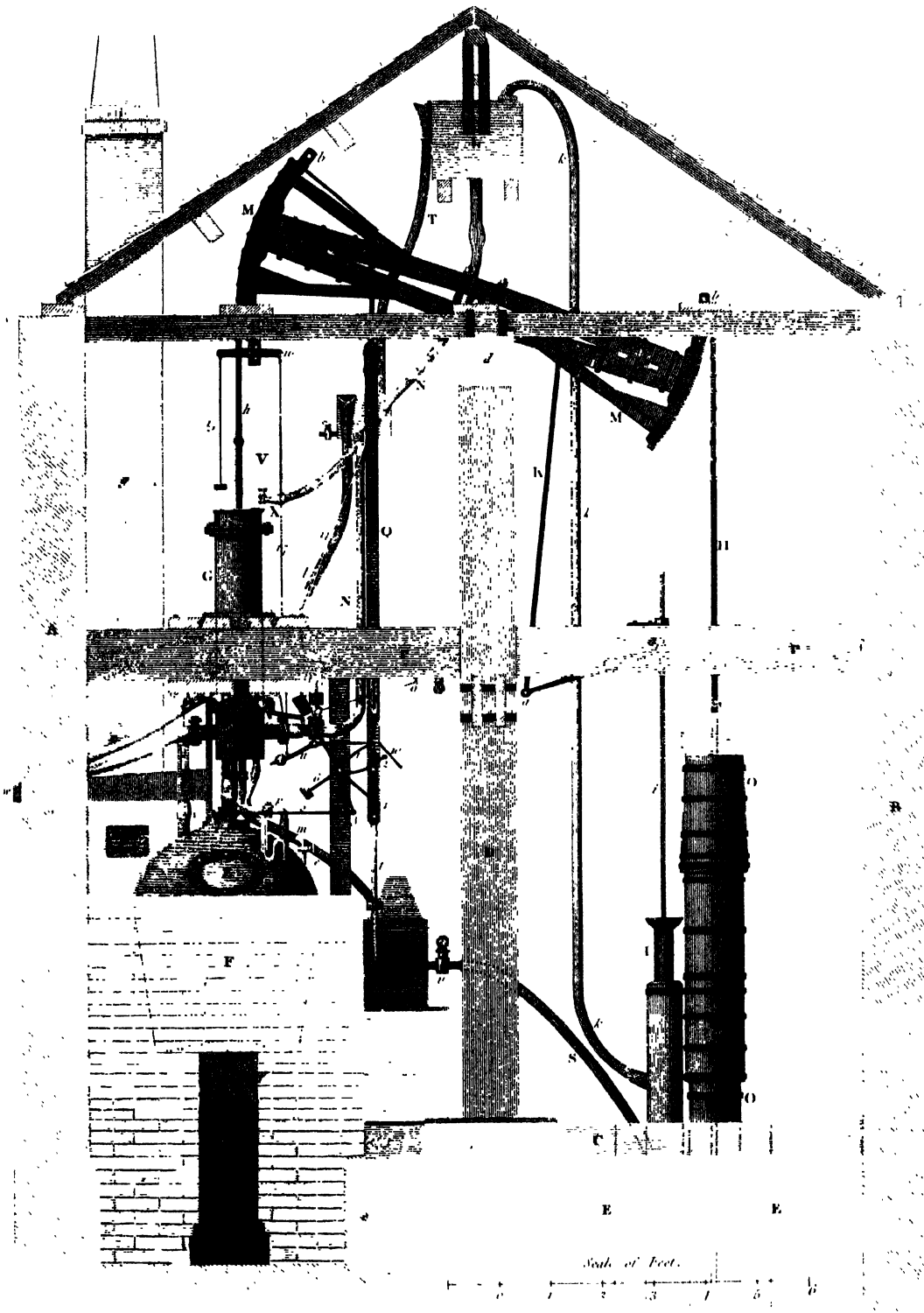
On returning to Paris, M. Betancourt made a model of a

double cylinder, on a scale of an inch to the foot; and, as he did not know the arrangement of Messrs. Boulton and Watt's valves, he invented those parts himself; and M. Perrier, from this model, constructed a large machine in 1790, at the isle of Cygnes, in Paris, for grinding corn. By examining the construction of this engine, which is fully described by M. Prony, it will appear that M. Betancourt made good use of his observations, for we find the engine to be the same as Mr. Watt's in every particular, except in the arrangement of the valves, which part is very defective, as both the steam-pipe and exhausting-pipe must be filled with steam, and emptied at each stroke, in addition to the content of the cylinder, without producing any effect to work the engine. A different construction by M. Betancourt, with two cocks, is also described, but it has the same defect, of which M. Prony was sensible; and in a second machine which he describes, points out the remedy, by varying the arrangement of the valves, so as to bring them very nearly the same as Mr. Watt's, though externally of different appearance. None of these engines have steam-jackets for the cylinders, nor is the expansion principle mentioned by M. Prony. The beautiful contrivance of the regulation by the flying-balls is not described, but all the engines are regulated by a water-cistern and pump, which we have here described. See also REGULATOR.

It is to be regretted, that none of our experienced engineers have undertaken to write a work on steam-engines, as there is not any subject in mechanics so interesting and useful.

Almost every introduction to philosophy contains a description of the atmospheric steam-engine, and most of the modern ones a short account of Mr. Watt's improvements; but these are in general very slight and defective; the best is in Brewster's edition of Ferguson's Lectures, which gives a sketch of Mr. Watt's double engine, with the parallel levers and rotatory motion; and we believe it was the first description published of that valuable invention, though it had been in general use for twenty-five years before. The engine is clearly described in the British Encyclopædia, 8vo.

STEAM ENGINE,
On the principle of Newcomen, as constructed by Smeaton.



Kier's
Fig. 1

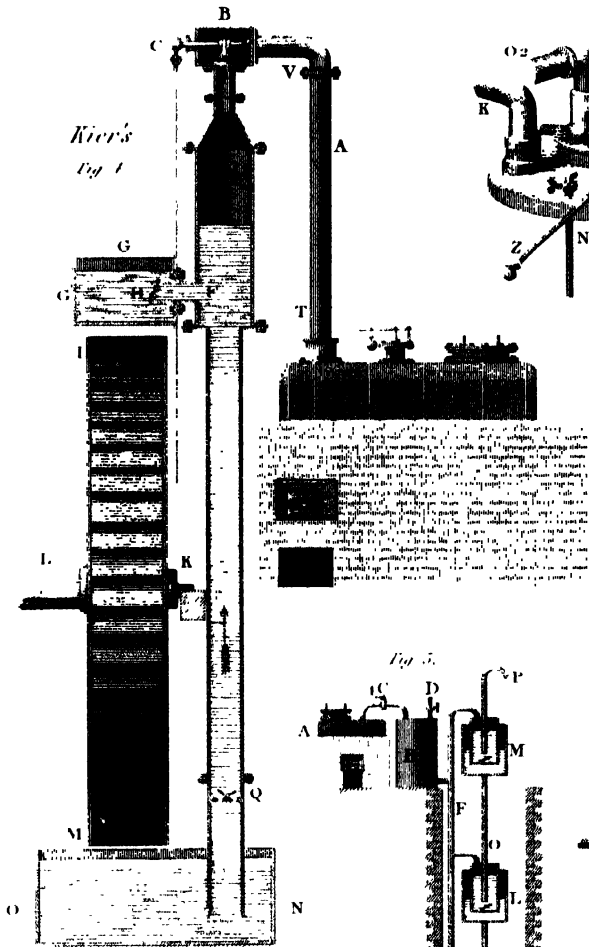


Fig. 5

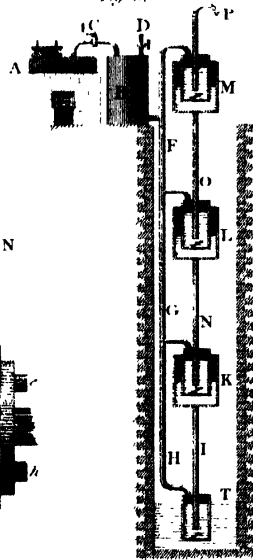
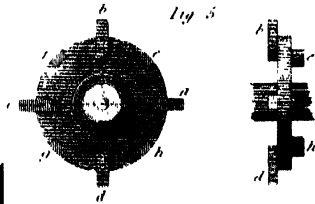
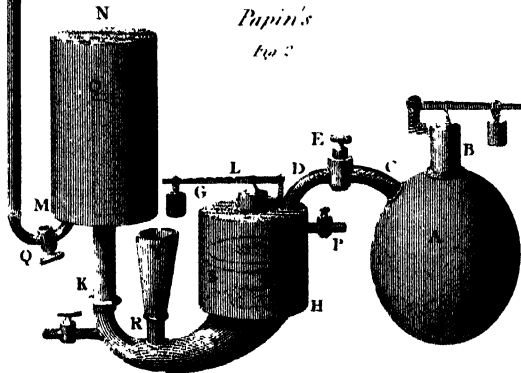


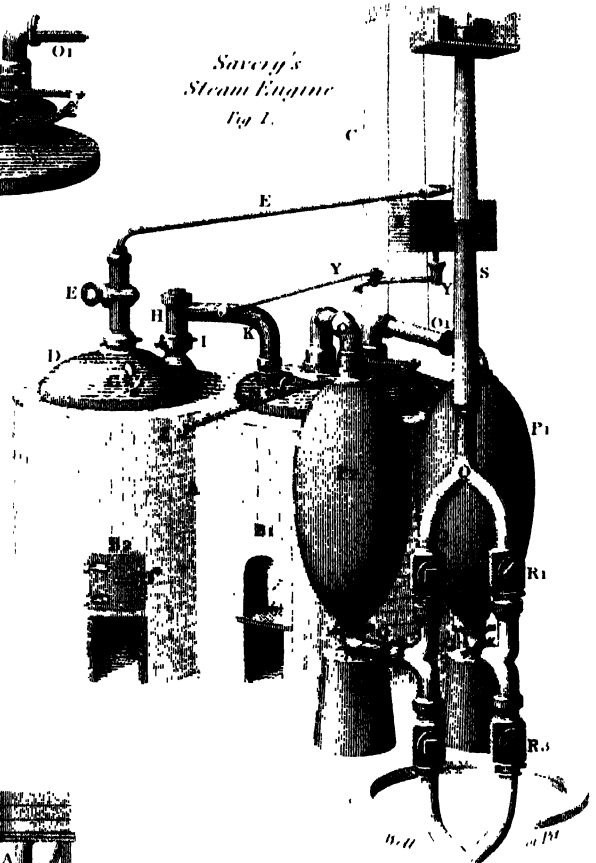
Fig. 6



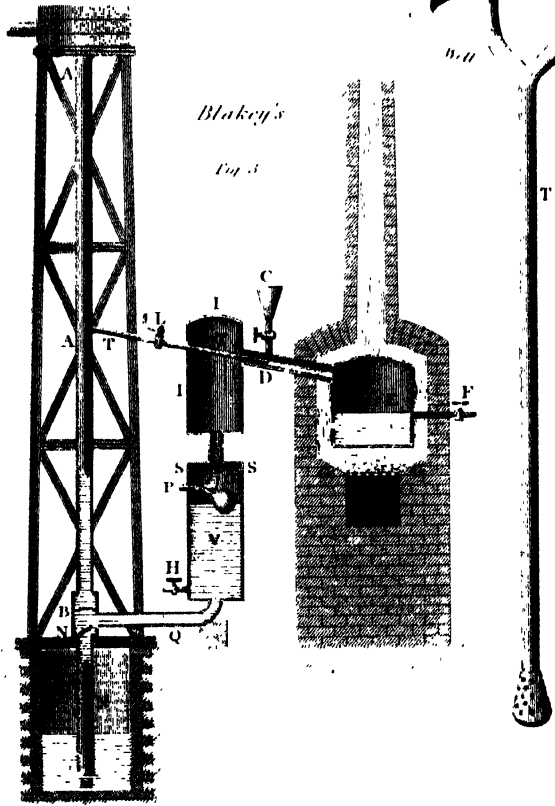
Papin's
Fig. 2



Savery's
Steam Engine
Fig. 1.



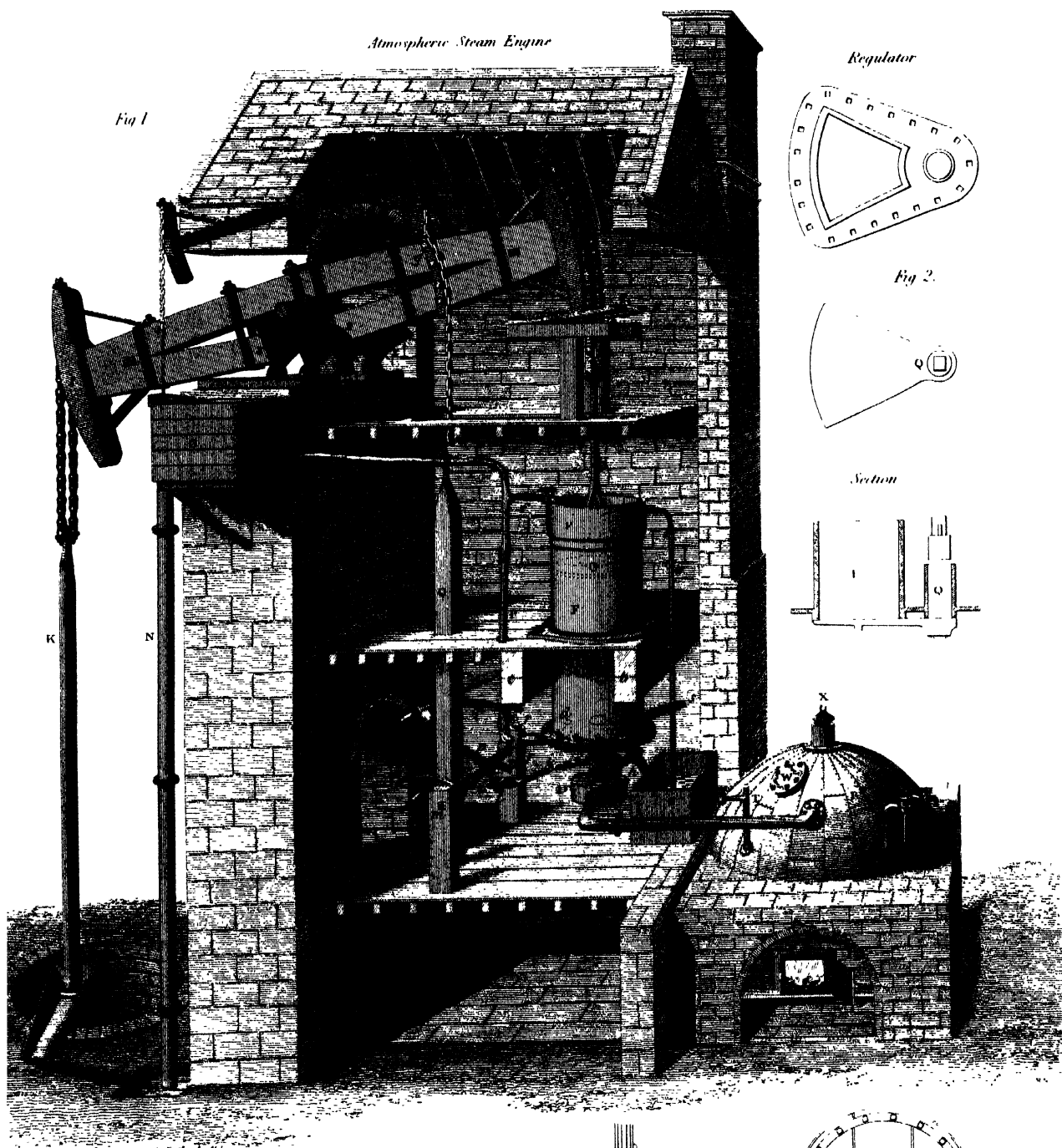
Blakey's
Fig. 3



STEAM ENGINE.

Atmospheric Steam Engine

Fig 1



Regulator

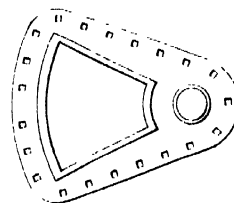
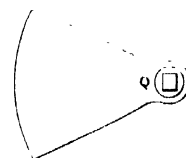
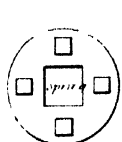
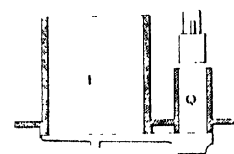


Fig 2.



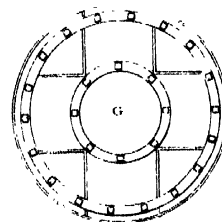
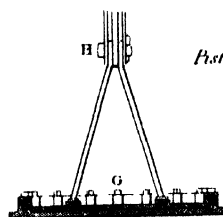
Section



*Injection Cap.
by Mr. Smeaton*



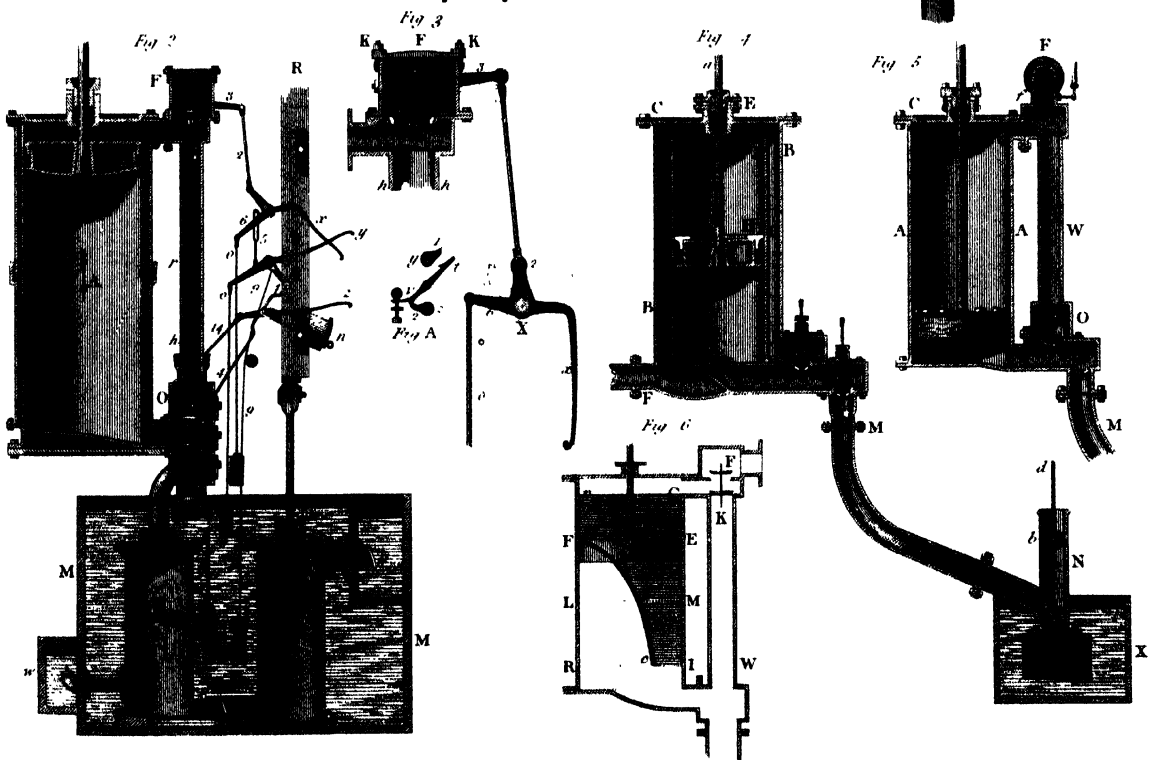
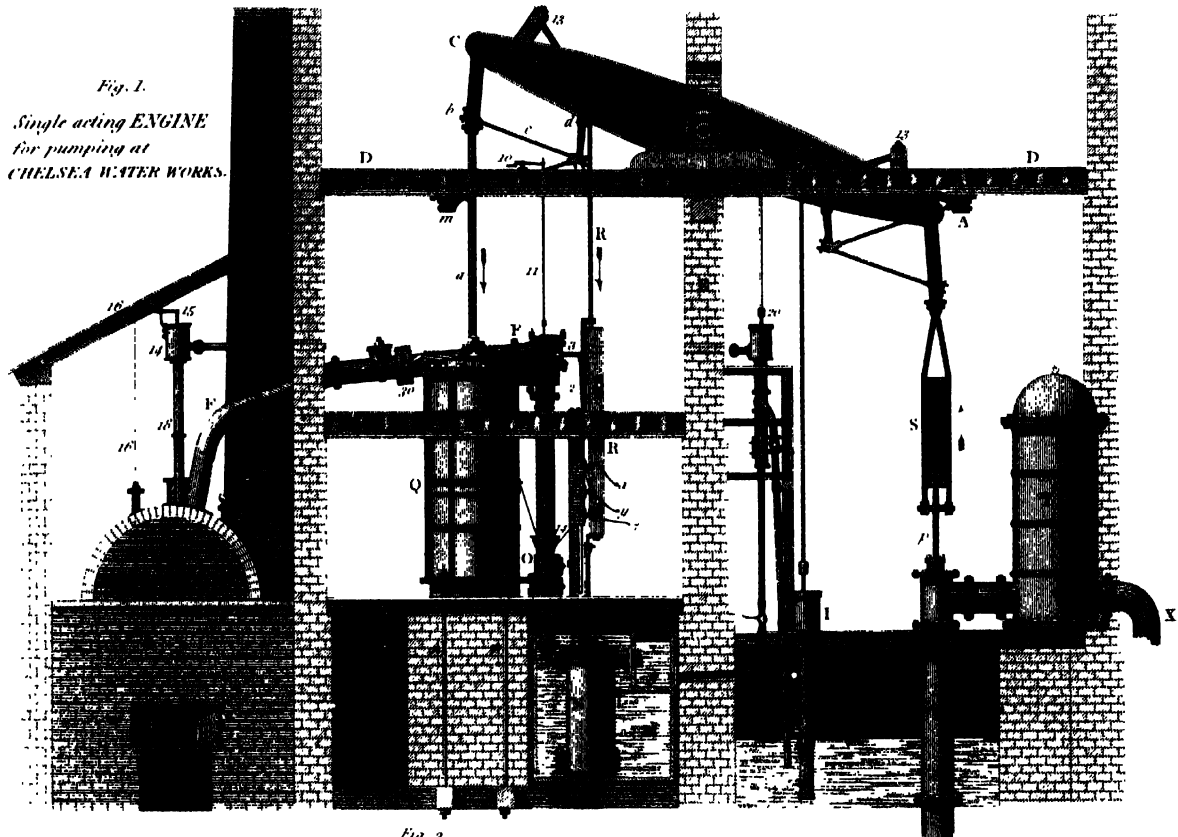
Piston



STEAM ENGINE.

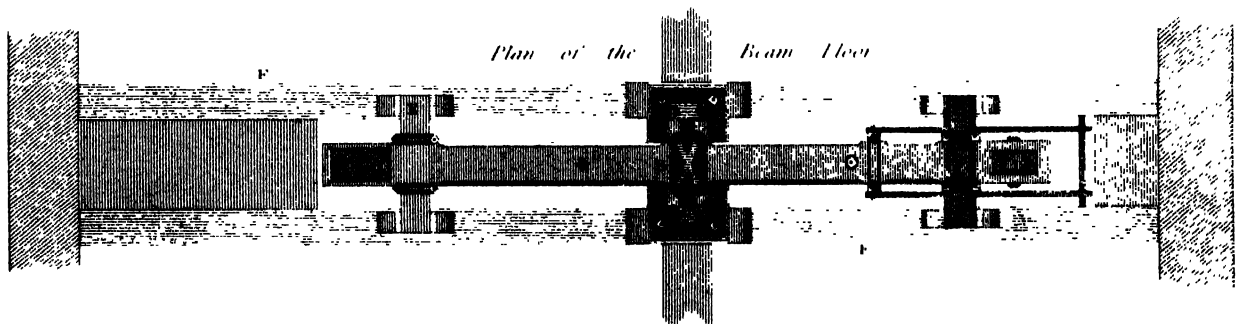
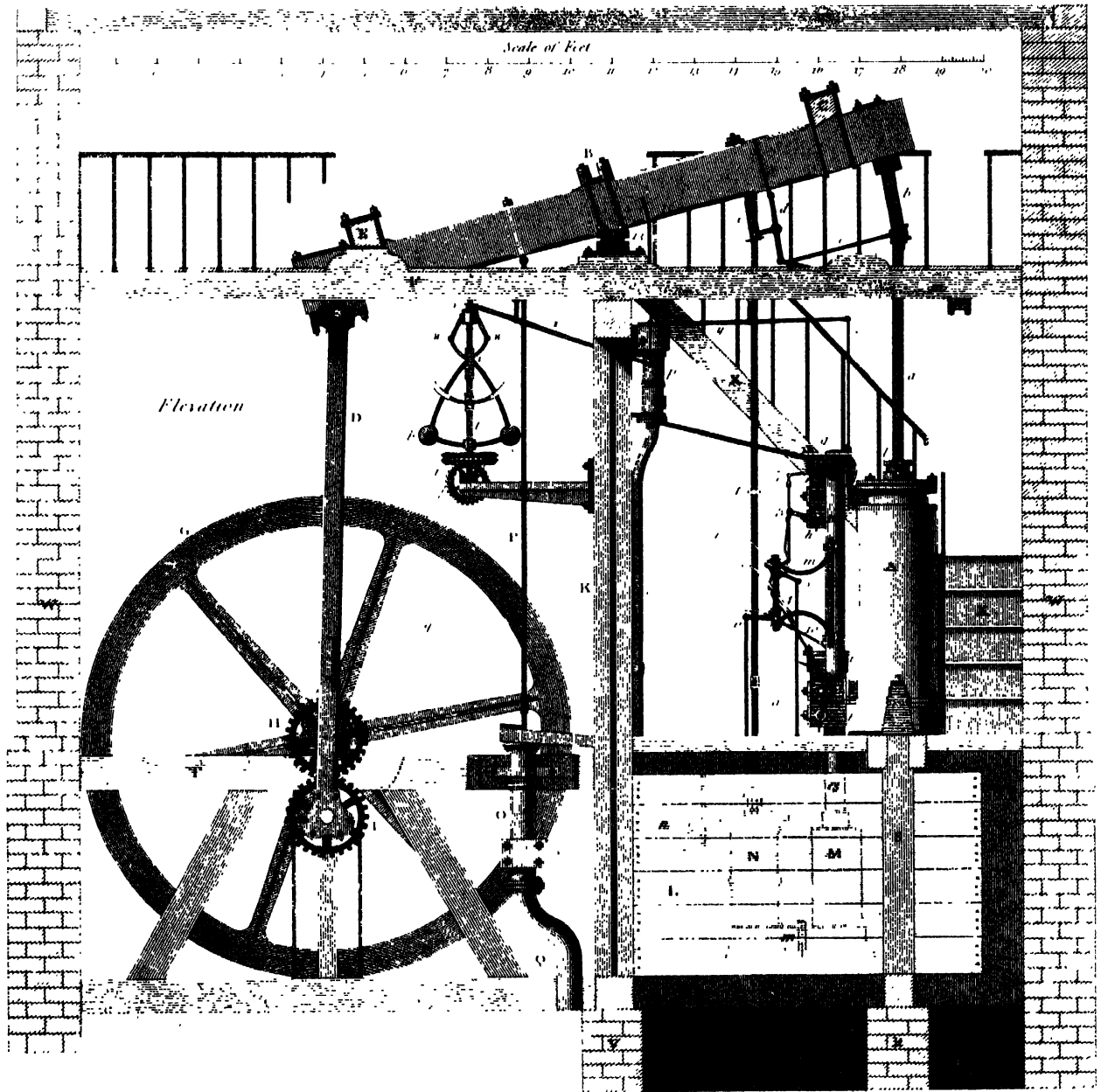
PLATE III & IV

M^r WATT'S ENGINE.



STEAM ENGINE.

Boulton and Watt's Engine on the original Construction.



STEAM ENGINE. PARALLEL MOTIONS.

PLATE III.

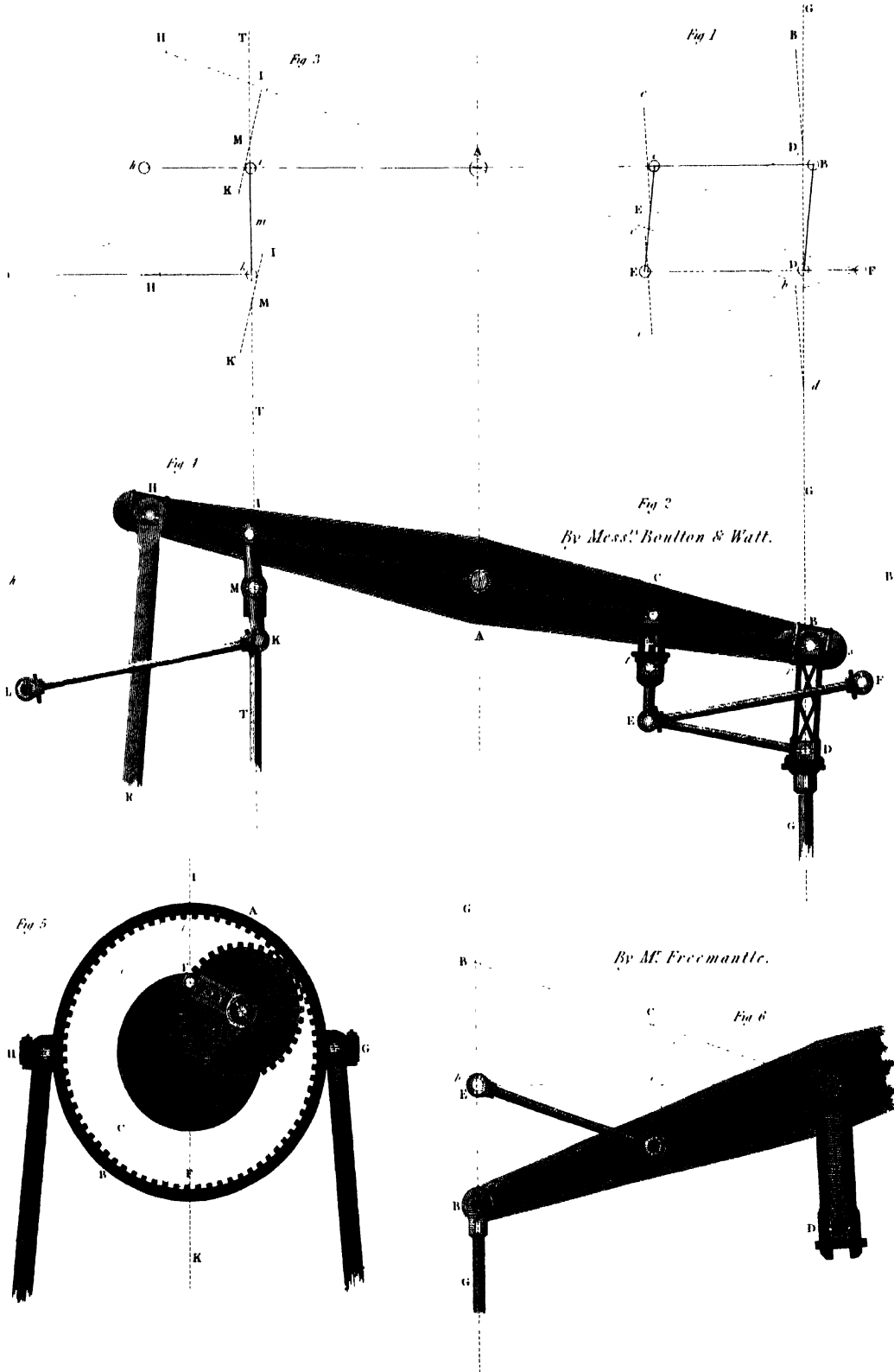


Fig. 1.

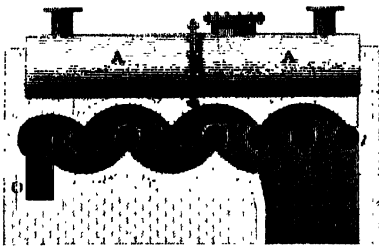


Fig. 1.

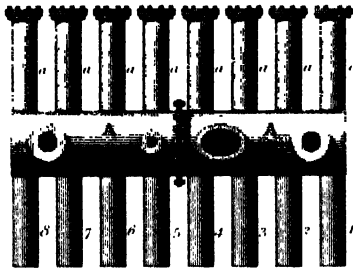
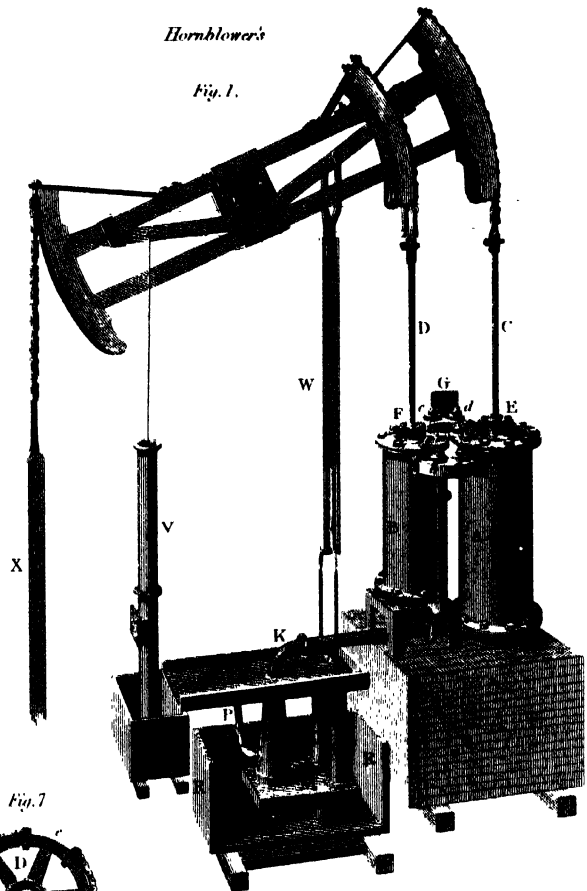


Fig. 2.



Hornblower's

Fig. 1.



Cartwright's

Fig. 8.

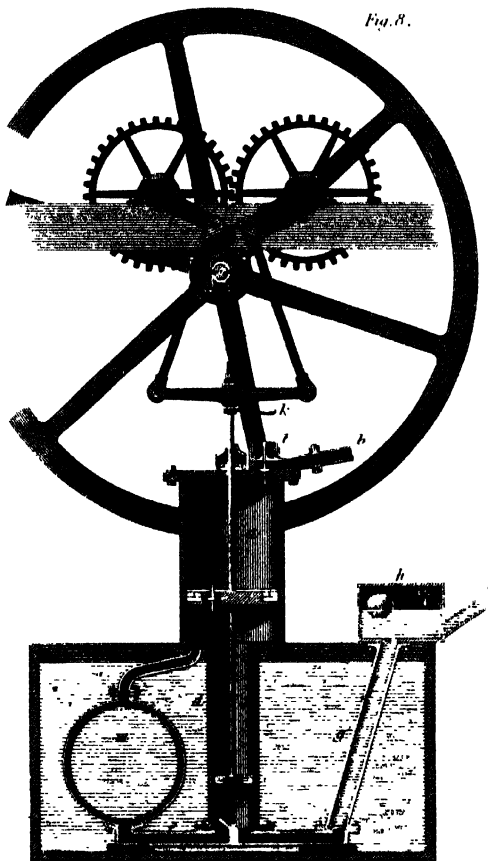


Fig. 7.

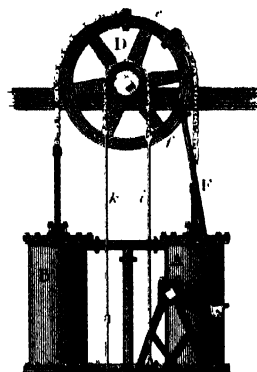
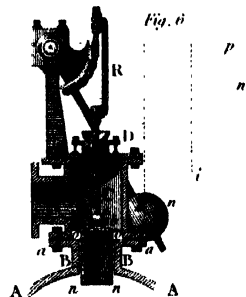
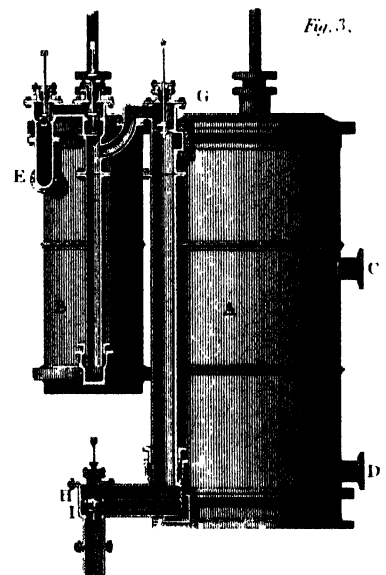


Fig. 6.



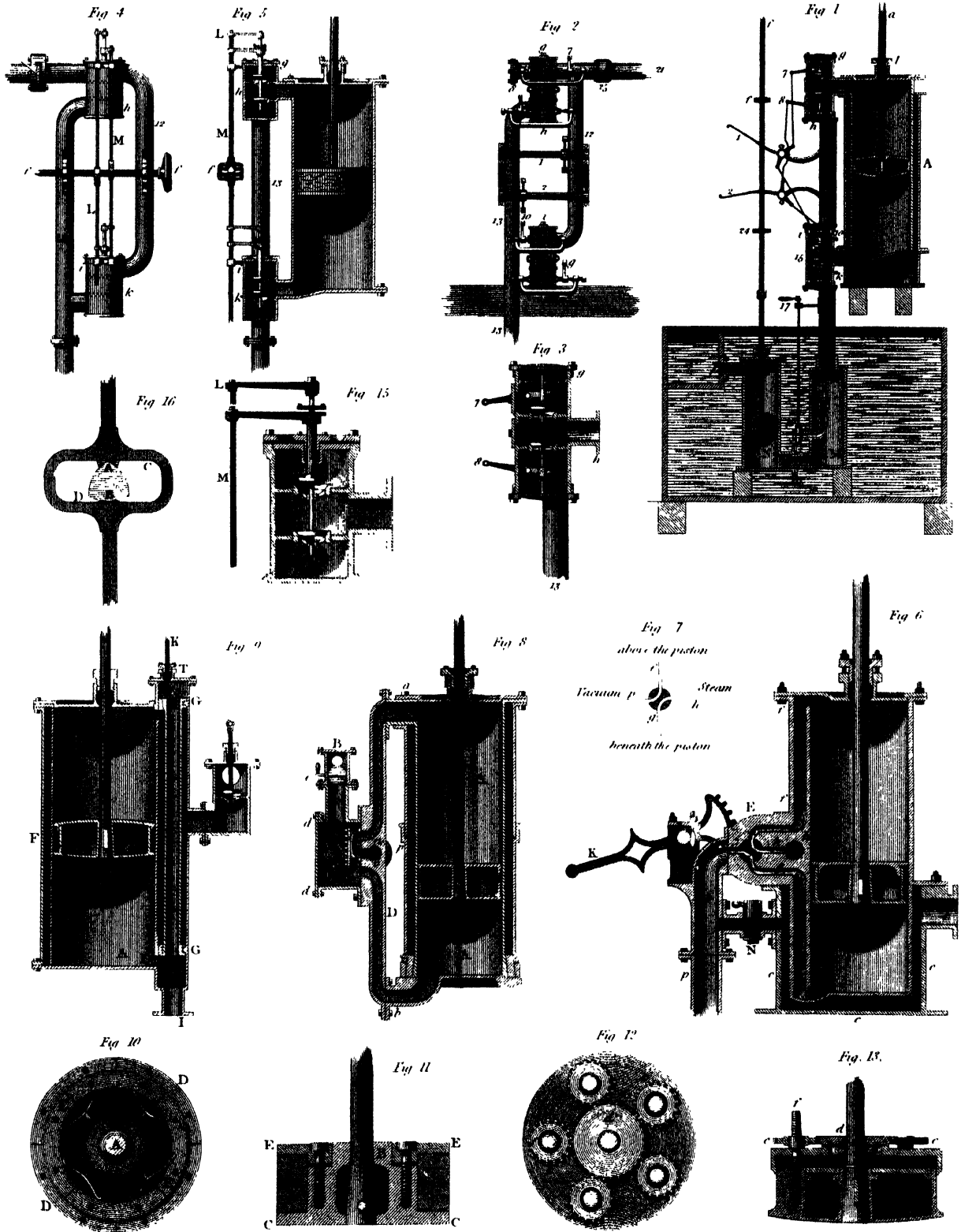
Woolf's

Fig. 3.



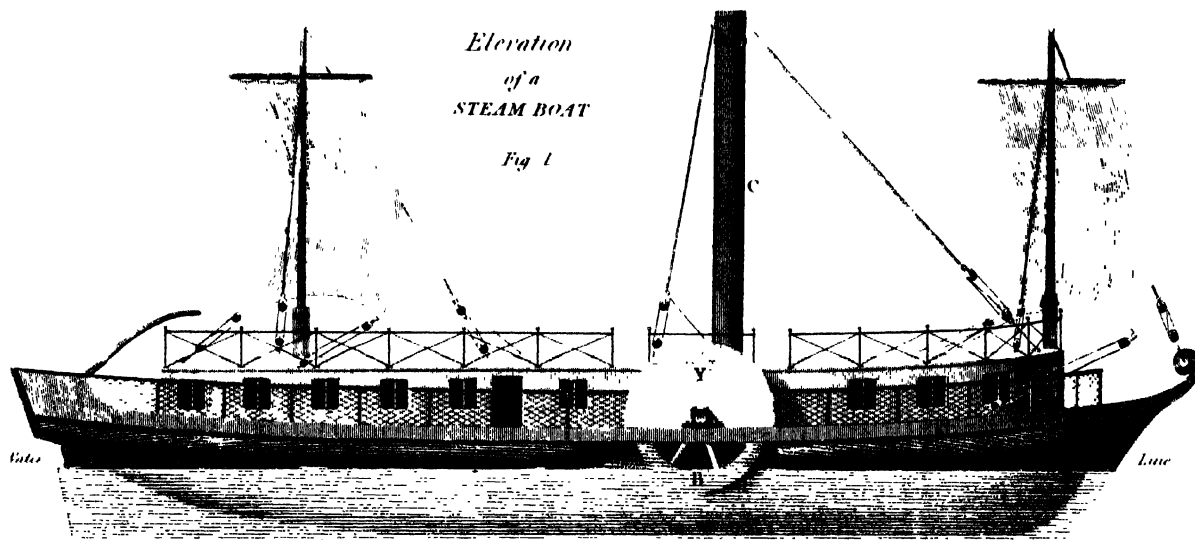
STEAM ENGINE,
CYLINDERS, PISTONS &c

PLATE VII.

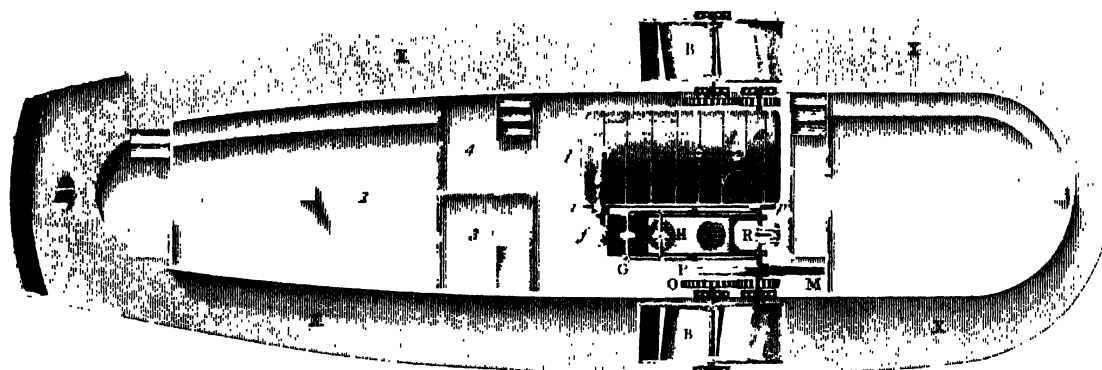


*Elevation
of a
STEAM BOAT*

Fig 1

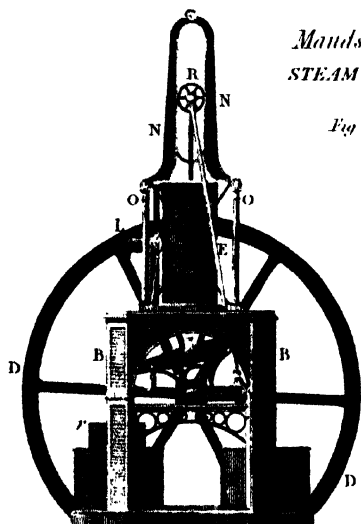


Plan Fig



*Maudslayi's
STEAM ENGINE*

Fig 3



*Murray's
STEAM ENGINE*

Fig 4

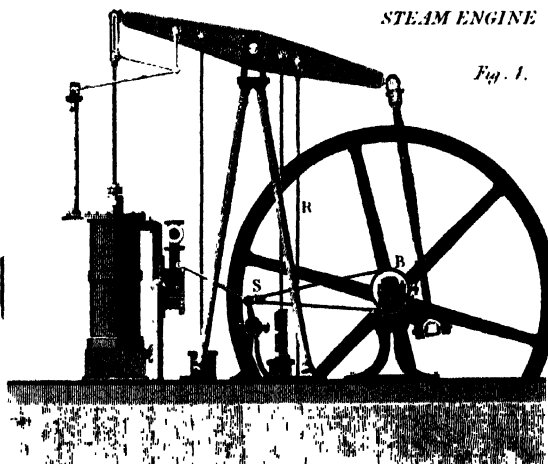
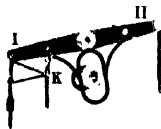


Fig 5

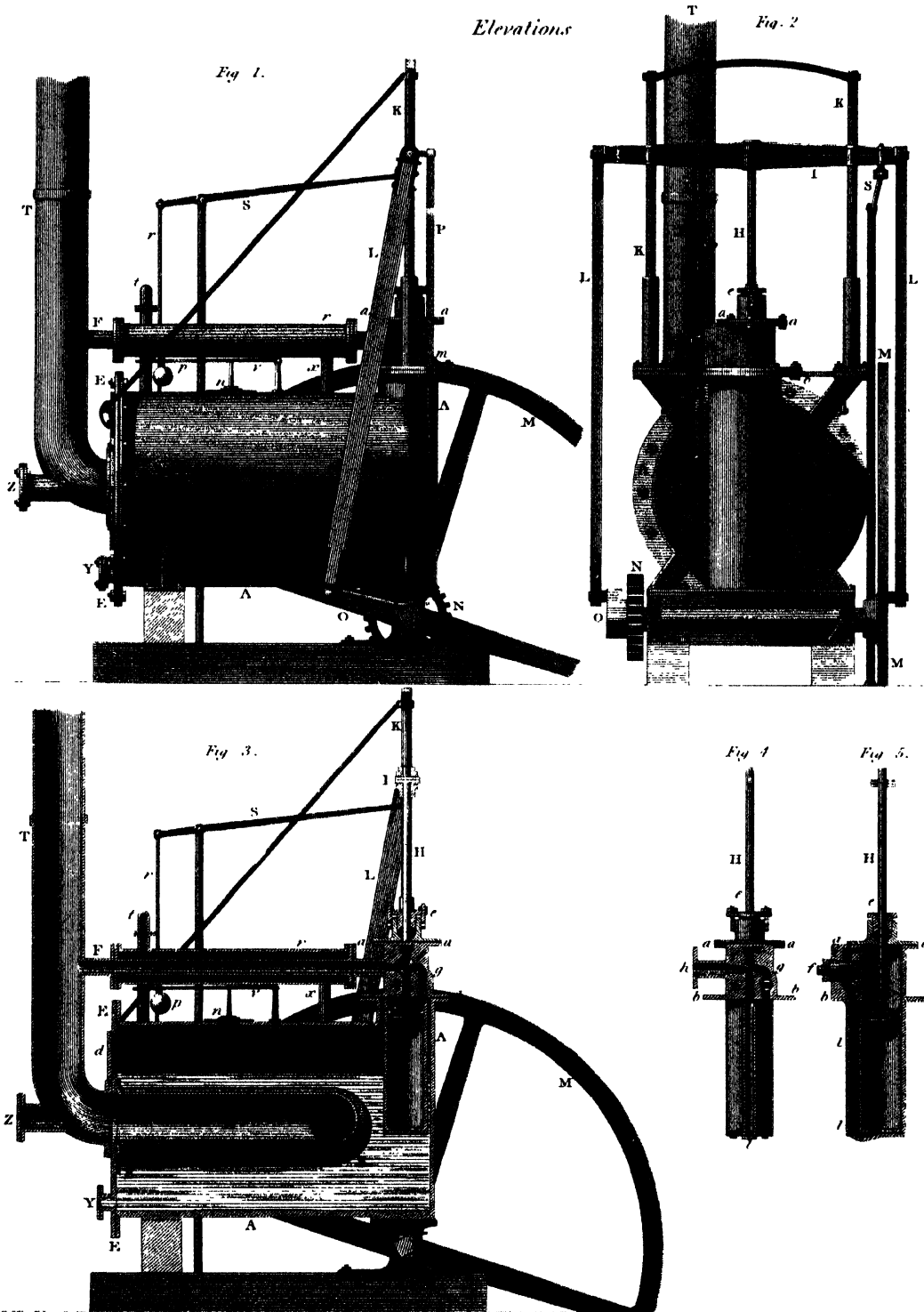


STEAM ENGINE

PLATE LX

High Pressure STEAM ENGINE used with the Dredging Machine on the River Thames.

Elevations



Steel

STEEL, in the *Arts*, a most valuable metal, consisting of iron combined with carbon. It is chiefly used for edge-tools, and other cutting instruments, and from its fine polish is used in ornaments of various kinds.

In chemistry it is called a carburet of iron.

Its hardness is greater than that of iron; and its most valuable property is, that it can be made harder than any other metal, by suddenly cooling it when heated to redness: also, if it is heated to a lower temperature than redness, and suddenly cooled, it becomes the most elastic of all the metals. It is of a darker colour when polished, and retains its polish much longer, not being so liable to oxydate.

The specific gravity of steel is greater than that of iron: thus, the spec. grav. of cast-iron is .72070; malleable iron, .77880; steel in its soft state, .78404; hardened steel, .78180.

Steel is manufactured by two processes, one in which the steel is made from pig-iron at once in the finery: this is practised in Germany, and is called natural steel. Cemented steel is formed by stratifying bars of iron with powdered charcoal in a close vessel, and by keeping the mass at a brisk red heat for a longer or shorter time, depending upon the size of the bars. This process is called *conversion*. The test of the conversion being complete is its blistered appearance, from which it has been called *blistered steel*. As the steel in this change does not undergo fusion, all the imperfections in the mechanical texture of the iron will still be found to exist in the steel. A drawing of the furnace employed for this process is given in *Plate VII. Iron Manufacture*; for the references to which, as well as the mill for tilting steel, see *TILTING of Steel*. It is from blistered steel that all the different kinds of steel are manufactured. These are principally of two varieties, viz. *cast-steel* and *shear-steel*.

Cast-steel is blistered steel fused and cast into ingots, which are afterwards drawn into rods by the hammer, or by rolling. By this change the steel becomes much harder, and of course entirely free from those seams and other defects which exist in the blistered steel: this is what renders cast-steel so much better for polished goods: for when blistered steel is attempted to be polished, the surface is seen to abound with numerous spots, arising from mechanical defects in the bars previous to conversion.

Cast-steel works much harder under the hammer, and will not bear much more than a red heat, without breaking in pieces under it. This, however, is more especially confined to that commonly made; since cast-steel may be made which will bear a white and even a welding heat; but it requires a much greater heat for its fusion, and would in consequence be sold at a higher price.

The refuse of blistered or common steel is generally melted into cast-steel; but this is not of the best quality. The best cast-steel is made by melting the bars of blistered steel, which, for this purpose, are a little more converted than for ordinary purposes, in order to give the steel a little more carbon than if it were used in the state of blistered steel. The bars are broken into small pieces, for the purpose of flowing the greatest quantity in the crucible.

The furnace employed for melting of steel is the best constructed air-furnace, and is similar in form to those used by brass and iron-founders in the small way, where the crucible is employed. That part of the furnace containing the crucible and the fuel is of a prismatic form, about twelve inches square, and two feet in length from the grate to

the top where the cover is placed. About three inches below the cover is a horizontal opening, called the throat of the furnace, which leads directly into the chimney. This opening is about three inches by six, and must never be less than the open part of the grate. In some manufactories, ten or twelve of these furnaces are at work at one time. The mouths of the furnaces are level with the floor of the room where the casting is performed. These are arranged along the two opposite walls, each containing a stack of high chimnies. The ash-pits of these furnaces terminate in a cellar below, which is well supplied with air. The crucibles in which the steel is melted are made on the spot. The material is Stourbridge clay, to which a little coke-dust is added. They are formed in a mould of cast-iron, of the form of the outside of the crucible. The proper quantity of tempered clay is first put into this mould, and then a wooden plug is driven in to form the inside of the crucible. They are then gradually dried, and slightly baked, at a much less heat than is given to the softest pottery. The crucible is generally removed from the baking fire to the furnace, which would be liable to crack if put into the fire cold. The crucible is placed upon a stand about four inches high, which is also placed upon the middle of the grate. The base of this stand is less in diameter than the upper part, in order to intercept the air the least possible. Each crucible is also provided with a flat cover, made very true on the under side, so as to fit. It is a little larger than the top of the crucible, in order to be easily removed with tongs. The cover is generally made of fire-clay a little more fusible than that of the crucibles. This admits of as much vitrification between the cover and the crucible, before the melting of the steel, as serves to keep out the air, which, at this high temperature, would injure the quality of the steel, by first destroying its carbon, and then oxydating the iron. In order, however, to guard more completely against this evil, some make use of what is termed a flux. This consists of any easily vitrifying substance, such as bottle-glass, in very small quantity. The substance now employed is the blast-furnace cinder.

The fuel used for melting steel is the coke of pit-coal, very highly baked in kilns used for the purpose. The fracture of these cokes is white and brilliant. They are so hard as to be sonorous; and their specific gravity is much greater than ordinary cokes. This coke, being broken into pieces about the size of an egg, is made to surround the crucible closely on all sides, and a few inches above the same. The heat required to melt steel is so intense, that if the fuel were not firm and dense, the fire would not last till the fusion took place. This would require a supply of cold fuel, which would not only endanger the crucible, but occasion great delay. When the steel is thoroughly fused, the crucible is withdrawn with a pair of long tongs, opening with two concave jaws to fit the cylindrical form of the crucible. The tongs are not removed till the metal is poured. Immediately on bringing it out of the fire, previous to which the cover is removed, some scoria, or refuse arising from the flux, is first removed. This exposes the steel to the action of the oxygen of the atmosphere. Particles of the metal are now seen to dart out of the crucible in bright convulsions, and these continue all the time the metal is pouring into the mould, causing a grand and interesting appearance. The mould is

of cast iron, giving an octagonal shape to the ingot. These moulds are of various forms. Those used for steel-plate are in the form of parallelograms: and those for making large saws are smaller at each end, in order to roll out into a plate nearly of the form of the saw.

The steel known by the name of shear-steel, has been so called from its application to the cutting part of sheep or wool shears. It was formerly manufactured at Newcastle-upon-Tyne, and has been called Newcastle steel. From being subjected to a similar process to the natural steel made in Germany, it has also been termed German steel.

We have before observed, that the bar-iron of which steel is made, contains many defects in its mechanical texture. In this state, it is said by the workmen to be loose, and is more or less so, as depending upon the management of the bar-iron maker. The manufacture of shear-steel consists in removing these defects, and at the same time giving it what is called increased fibre by the operation of hammering.

The first preparation is to lay a number of bars of blistered steel together, and bind them with iron rings at one end, so that the bars which are put in the fire may not be displaced. A portion of these united bars is now to be heated to a full welding heat, keeping the surface well defended by throwing powdered sand upon it from time to time. This fuses with the oxyd of iron, forming a liquid coating, which defends the surface from the action of the air. If this precaution is not observed, the steel, when heated to the degree of welding, would become what is termed *burnt*, and its malleability be impaired. In the welding state it is placed under a forge-hammer, working by water or a steam-engine; when the bars become firmly united, and all the loose parts previously existing in the malleable iron are, at the same time made sound. When a little more than half the length of the bars is treated in this way, the iron rings are removed, and the other end heated and hammered in a similar way. The welded mass is now drawn down into small bars about an inch and a quarter broad, and three-eighths or half an inch in thickness. In this state it is sold to the consumer, who afterwards has it reduced to different sized rods by the tilt-hammer. The steel is rendered so compact in texture by the welding and hammering, as to become susceptible of a much better polish than blistered steel is capable of; at the same time that its tenacity and malleability are much improved. The former improvement highly fits it for table-knives: the latter makes it valuable for springs of various kinds, particularly those of gun-locks.

The process by which this steel is formed has another

advantage besides rendering it sound and more malleable. It is found softer and more kind than the blistered steel from which it is formed, and is much more uniform in its quality. This may be explained by the fact, that a quantity of the carbon of the blistered steel is dissipated in the form of carbonic acid during the welding and hammering, by which a steel is obtained, having a less than ordinary proportion of carbon, and is in consequence less liable to break in bending, and at the same time softer and more flexible. Indeed, if the process of welding and hammering were repeated several times, the steel would lose the whole of its carbon, and become pure iron.

Blistered steel should not be used but for the commonest purposes, where great tenacity of polish is not an object. For all nice purposes, where great tenacity and soundness are necessary, shear-steel should be employed; and where a fine polish or great hardness is wanted, cast-steel is indispensable. See IRON and CUTLERY.

STEEL, *Annealing*, or *Nealing of*, is for the softening it, in order to make it work easier; which is usually done by giving it a blood-red heat in the fire, and then taking it out, and letting it cool of itself.

Some have pretended to secrets in annealing, by which they could bring down iron or steel to the temper of lead: this was to be done by often heating the metal in melted lead, and letting it cool again out of the lead. But this method has no other effect than what is obtained from the former, when the cooling is very gradual.

Steel may indeed be made a little softer than in the common way, by covering it with coarse powder of cow-horn, or hoofs: thus inclosing it in a loam, heating the whole in a wood-fire till it be red-hot, and then leaving the fire to go out of itself, and the steel to cool, which it will do slowly from being inclosed. See TEMPERING, and STEEL, *supra*.

For the expansion of steel by heat, see PYROMETER.

STEEL-*Glasses*, a name given by some authors to the metal-line spheres used in optics. These, according to Cardan, are made of three parts of brass, one part of tin, and one of silver, with an eighteenth part of antimony; but most either totally leave out the silver, or add only a twenty-fourth part, to save the expence. There are many other methods, directed by several authors, but most use arsenic and tartar, mixed with the metals. These are afterwards to be polished with emery, rotten-stone, putty, and the like.

STEEL-*Ore*, is used to signify a particular kind of lead-ore.

Stereotype Printing

STEREOTYPE PRINTING. This art having of late years come very much into use, we shall give a short sketch of its *history, practice, and advantages.*

The method of printing linen and paper-hangings has been known in the East from time immemorial. Printing on wooden blocks, which is the mode now used by paper-stainers, has been practised fifteen or sixteen hundred years in China. According to this plan, when an author means to print his work, he has it fairly transcribed upon a thin and semi-transparent paper. Each leaf is then reverfed upon a smooth block of hard wood, upon which the engraver cuts the characters in relief. There must, therefore, be a separate block for every page. About the close of the 14th century, the Italians, Germans, Flemings, and Dutch, began about the same time to engrave on wood and copper, but the previous advances had been gradual. The inscriptions in relief, upon monuments and altars, in the cloisters, and over church porches, served as models for block-printing. The letters upon painted windows resemble those in the books of images. The invention of cards was probably an intermediate step; and it has been inferred, as well from edicts civil and ecclesiastical, as from the figures on the cards, that these were first brought into use about the year 1376, to amuse, it is said, Charles V. of France. By the shape of the crowns, and the sceptres with the fleur-de-lis, it has been thought they were invented by the French; but the names of the suits rather imply, that they are of Spanish or Italian origin. At first cards were painted, but about the year 1400, they were printed from wooden blocks. To this we may directly trace the art of printing. The books of images, which form the next step, were printed on wooden blocks: one side of the leaf only is impressed, and the corresponding text is placed below, or on the side, or proceeding from the mouth of the figure. Of these scarce books, Lambinet gives the following enumeration: 1. "*Figuræ typicæ veteris atque antitypicæ Novi Testamenti*," which in Germany is called the Bible of the poor, because it was originally intended as an abridgment of the scriptures, for those who could not purchase, or who had not leisure to read the whole. There is a copy of this work in the Bodleian library, and another at Christ's college, Cambridge. 2. "*Historia S. Joannis Evangelistæ, ejusque visiones evangelistæ, ejusque visiones apocalypticæ.*" 3. "*Historia seu Providentia Virginis Mariz, &c.*" 4. "*Ars moriendi.*" 5. "*Ars memorandi notabilis per figuras Evangelistarum.*" 6. "*Donatus, seu grammatica in usum scholarum conscripta.*" 7. "*Speculum humanæ salvationis.*"

It is almost certain, therefore, that from the cotton and silk-printing of the Indians, the Chinese block-printing, and the books of images just alluded to, and perhaps from the mode of writing among the bards, who cut their poems upon bars of wood, and which they call carving a book, the idea of stereotype printing is not of modern origin. That it was prior to the art of printing by moveable types there can be no doubt, since this latter mode of printing was first suggested by the Catholicon, which was printed with wooden tablets, in a series, and composed in forms. This mode of printing, except in China, where it is still practised, was laid aside soon after the invention of the

common letter-press printing.

The history of the modern stereotype is involved in some obscurity. In the Philosophical Magazine is the following account: "Above a hundred years ago, the Dutch were in possession of the art of printing with solid or fixed types, which were in every respect superior to that of Didot's stereotype. It may, however, be easily understood, that their letters were not cut in so elegant a manner, especially when we consider the progress which typography has made since that period. Samuel and J. Leuchtmans, booksellers at Leyden, have still in their possession the forms of a quarto bible, which were constructed in this ingenious manner. Many thousand impressions were thrown off, which are in every body's hands, and the letters are still good.

"The inventor of this useful art was J. Vander Mey, who resided at Leyden about the end of the 16th century. With the assistance of Muller, the clergyman of the German congregation there, who carefully superintended the correction, he prepared and cast the plates for the above-mentioned bible, in 4to. This bible was published likewise in folio with large margins, ornamented with figures, the forms of which are still in the hands of Elwe, a bookseller at Amsterdam; also an English New Testament, and Schaaf's Syriac Dictionary, the forms of which were melted down: likewise a small Greek Testament, in 18mo. As far as can now be ascertained, Vander Mey printed nothing else in this manner; and the art of preparing solid blocks was lost at his death, or at least was not afterwards employed." The Dutch editor supposes, that the reason why Vander Mey's invention was dropped was, that the process was too expensive.

In the year 1781 was printed, by Mr. Nichols of London, a pamphlet, entitled "*Biographical Memoirs of William Ged*," including a particular account of his progress in the art of block-printing. The *first* part of the pamphlet was printed from a MS. dictated by Mr. Ged just previously to his death: the *second* part was written by his daughter, for whose benefit the profits of the publication were intended: the *third* is a copy of proposals issued by Ged's son, in 1751, for reviving his father's art; and to the whole is added Mr. More's narrative of block-printing. It should seem from this publication, that in the year 1725, Mr. Ged began his scheme of block-printing. In 1727 he entered into a contract with a person who had a small capital, but who, alarmed at the supposed risk of losing the little which he had, abandoned the concern, after he had expended little more than twenty pounds. In 1729 he entered into a more promising partnership with a Mr. Fenner, Mr. Thomas James, a type-founder, and John James, an architect. Some time after a privilege was obtained from the university of Cambridge to print bibles and prayer-books; but it appears, that one of his partners was actually averse from the plan, and, to thwart the project, engaged such people for the work as he thought most likely to spoil it. One of his people who was entrusted with the secret, avowed, that all the books printed in stereotype had been purposely made incorrect, in consequence of which they were suppressed at the university, and the plates sent to the king's printing-house, and from thence to Caillon's foundry. "After much ill usage," says the

STEREOTYPE PRINTING

writer in the Philosophical Magazine, "Ged, who appears to have been a person of great honesty and simplicity, returned to Edinburgh. His friends were anxious that a specimen of his art should be published, which was done by subscription. His son James, who had been apprenticed to a printer, with the consent of his master set up the forms in the night-time, when the other compositors were gone home, for his father to cast the plates from, by which means Sallust was finished in 1736." A copy of this work is in Mr. Tilloch's possession, and also a plate of one of the pages from which it was printed. Another work was also printed from plates manufactured by Mr. Ged; this was the well-known book entitled "The Life of God in the Soul of Man," which has the following imprint; "Newcastle, printed and sold by John White, from plates made by William Ged, goldsmith in Edinburgh, 1742."

Fifty years after the invention of plate-printing by Mr. Ged, Mr. Tilloch tells us he made a similar discovery, without having at the time any knowledge whatever of Ged's invention. He was aided in bringing his discovery into practice by Mr. Foulis, printer to the university of Glasgow. They overcame every difficulty, and were able to produce plates, the impressions of which were as perfect and handsome as those of the types from which they were cast. Though we had reason to fear, says Mr. Tilloch, from what we afterwards found Ged had met with, that our efforts would experience a similar opposition, we persevered in our object, and took out patents for England and Scotland, to secure to ourselves, for the usual term, the benefits of our invention; for the discovery, he adds, was as much their own, as if nothing similar had been practised before. Ged's knowledge of the art may be said to have died with his son, whose proposals for reviving it, published in 1751, not having met with encouragement, he went to Jamaica, where he died. Owing to circumstances of a private nature, not at all connected with the stereotype art, the business was laid aside after some few volumes had been stereotyped and printed under the direction of Messrs. Tilloch and Foulis.

Some time elapsed, when M. Didot, a French printer, applied the stereotype art to logarithmic tables, and afterwards to several of the most popular classics, such as Virgil, Horace, &c. and to various French publications. On this account, the French lay claim to the invention, but surely without even the appearance of justice. About the year 1800, Mr. Wilson, a printer in London, engaged with earl Stanhope, for the purpose of bringing the stereotype art into general practice. His lordship is said to have had some communications with Mr. Tilloch on the subject, and afterwards to have received the personal attendance of Mr. Foulis at his seat, at Chevening, in Kent, where the noble earl was probably initiated into the practical part of the operation, and for which, we have heard, he paid 700*l.* as a remuneration.

After some years application, Mr. Wilson, who at that time lived in the neighbourhood of Lincoln's-Inn-Fields, but who afterwards removed to St. Pancras, and carried on the business on a very extensive scale, announced to the public, that the genius and perseverance of earl Stanhope had overcome every difficulty; and that accordingly, the various processes of the stereotype art had been so admirably contrived, combining the most beautiful simplicity, with the most desirable economy, the *ne plus ultra* of perfection, with that of cheapness, as to yield encouragement to the public for looking forward to the happy period when an application of this valuable art to the manufacture of books would be the means of reducing the price of all

standard works, at least thirty, and in many cases forty, *per cent.*

In 1804, Mr. Wilson offered, upon certain terms advantageous to himself, the stereotype art to the university of Cambridge, for their adoption and use in the printing of bibles, testaments, and prayer books. Some differences between the syndics and the printer caused the contract to be dissolved. Into these disputes it is not our business to enter; it will be sufficient to add, that at present, at Oxford as well as at Cambridge, the stereotype art is adopted, and thousands of bibles, &c. issue annually from their presses, printed on that plan.

The practice of stereotype printing is readily described: a page of any work is set up in the usual mode of printing, (see the article PRINTING,) from which a mould of plaster, similar to plaster of Paris, is taken off, and from this a plate in type metal, from which the stereotype print is worked. Of course the whole is set up in distinct pages, which are to be put together in the usual way before a sheet is worked at press.

It is evident, therefore, that the beautiful specimens of stereotype printing sometimes exhibited, and which have induced many persons to ascribe that merit to the art, does not in reality belong to it. A stereotype plate is a facsimile of the page from which it was taken, and consequently cannot exceed in beauty the original type. Stereotype, therefore, can give no additional beauty to printing: this depends on the taste of the letter-founder, and the care of the pressmen. Those who produce fine specimens of stereotype printing, could also give others equally good with the moveable types from which the plates are cast.

The metal of which the plates are to be cast is a compound of regulus of antimony and hard lead, or tea-chest lead. The general method of mixing the metal is to take one hundred weight of regulus of antimony, and break it into small pieces, separating from it all dust and dirt, and then add to it from five to eight hundred weight of hard lead, according as the metal is required to be more or less hard. The lead is to be melted over a slow fire, and when melted, and the scum taken off, the regulus is to be put in. To every hundred weight of lead may be added a pound or two of block-tin, but this is not necessary.

In casting the plates, as in every other casting, a mould must first be made, so as to form the counterpart of the original type. The substance required for this must be of so delicate a texture when soft, as to be capable of receiving an impression from the finest lines: and when dry, it must be capable of bearing the action of melted metal. These qualities will be found in gypsum or plaster of Paris. Gypsum in the rock, as it is called, which is the best, is plentiful in Nottinghamshire. It has been observed, that this substance, when pulverized and mixed with water, soon becomes very hard, and will bear almost any degree of heat; but it contracts when exposed to fire, and is liable to warp. It is also extremely difficult to expel the air and moisture which it rapidly absorbs, and tenaciously retains. These are defects respecting the process of casting, which require to be corrected by compounding it with other substances less absorbent than itself. But whatever be added to it must be capable of a fine surface, so as to preserve a perfect polish on the plate to be cast. The following process has been recommended: dissolve a quantity of common whiting in a tub of clean water, and make it of the consistence of what is generally used in white-washing. Mix the plaster with this solution, and it will contract but little from the heat; the air and the moisture will be expelled with greater ease,

and the mould will not be so liable to crack as the plaster would alone.

In making a perfect mould for the page to be cast, a frame of cast-iron must be prepared, nearly half an inch wider and longer than the page or pages locked up in the chases. The frame determines the thickness and strength of the mould, and requires to be nearly an inch deep. To this must be added four cubic pieces of metal, whose height should be exactly four-fifths of the height of the letters. On the height of these, the thickness of the stereotype plate depends. The pages in the chases are now to be laid flat upon the moulding table, and the letter, if necessary, is to be planed down to an even surface. In the openings of the four corners of the page are to be placed the four pieces of metal, on which the frame is to rest when laid over the page.

To prevent the adhesion of the plaster, it will be necessary to oil the face of the page with a soft brush; then take a quantity of the white-wash into a wooden bowl, and add to it so much fine plaster as will make it into a thin paste. When reduced to an equal consistency, apply it to the face of the letter with a painter's brush, so as to fill every cavity, and then pour on the remainder of the plaster to fill the frame. When beginning to harden, strike off the superfluous plaster with a straight metal rule, and the back of the mould will be smooth and regular. The mould is next to be separated from the page, and to be dried in an oven.

In casting the plates, the dried mould is to be laid in a pan about two inches deep, with the face upwards, and a small moveable screw is to be placed at each side or end of the pan to furnish a press on the frame which contains the mould, and prevent the rising up, and the metal is applied over the mould in the pan, and carried to the oven, in which it should remain from one to two hours, to acquire an equal degree of heat; for on the principle of equal temperature between the metal and moulds, the success of the operation wholly depends. And unless the oven be kept sufficiently hot to raise the temperature of the moulds to that of the melted metal, the experiment cannot succeed.

Such is the fineness of the composition of the moulds, and such the accuracy of the process, that plates may be cast from the finest engravings as perfect as the copper-plate itself, and might be worked in the same manner, could it be cleaned after each operation with the same facility, and if the metal did not discolour the paper. Wood-cuts, ornaments, &c. are cast in the same manner, perfectly correct. The art has also been applied to the printing of music.

When the pages are returned from the foundry, they require to be thoroughly cleaned; for if the oil be suffered to remain on the letter, it will not only be disagreeable to distribute and compose, but the dirt which adheres to it will spoil the next mould to be made from it; hence it is necessary that the letter be thoroughly cleaned with boiling water and a brush, which increases the expences attached to this art very considerably.

After a plate has been cast, a few small imperfections will frequently be discovered; such as that the eye of the *e*, or similar letters, may have been full of dirt when the mould has been taken; of course the plate will exhibit those parts filled with metal, which now require to be corrected. A workman, called a *picker*, takes the plate, and after clearing it of all superfluous metal, pulls a proof, marks the defects, and proceeds to make the requisite alterations in a manner that will now be easily understood. If, in the course of the work, any damage be done to the plate, or any letter or word be broken, the picker cuts it out, and inserts in its place a

moveable type. This is very practicable, and only requires the letters to be cut square, so that the type may exactly fit the place. In this way a letter, a word, or even a line, may be taken out and corrected without injuring the plate. The plate is now ready for the press, and may be laid on blocks, and fastened down with a slip of brags and a screw.

With respect to the advantages to be obtained by the stereotype over the common mode of printing, it may be observed, that the calculations of Mr. Wilson, already referred to, of an actual saving of 30 or 40 per cent. seem to have been much over-rated. Mr. Brightly, who practised the method of stereotype for some years, having made several estimates, and being himself a printer as well as publisher, could have no inducement to give an exaggerated statement on either side of the question, seems to doubt if there be any saving whatever by the new process. Among others, he has given the estimate of the expences of a work printed in both ways, equal to twenty sheets octavo, of which 1000 copies are sold annually. Here he assumes, that in the common mode, the 4000 copies must be worked at once, but according to the stereotype plan, 500 copies are to be worked every six months, to save the interest of money. Supposing the paper in both cases to be thirty shillings per ream, the calculation is as follows:

Price of Common Printing.

	£	s.	d.
Composition	14	0	0
Reading	3	10	0
Press-work	24	0	0
<hr/>			
Other expences and profits	41	10	0
	20	15	0
<hr/>			
One hundred and sixty reams of paper	62	5	0
	240	0	0
<hr/>			
Interest of money for the first half year	302	5	0
Ditto for the second half year - -	7	11	0
Ditto for the third half year - -	6	12	1½
Ditto for the fourth half year - -	5	13	3
Ditto for the fifth half year - -	4	14	4½
Ditto for the sixth half year - -	3	15	6
Ditto for the seventh half year - -	2	16	7½
Ditto for the eighth half year - -	1	17	9
	0	18	10½
<hr/>			
	336	4	6

Price of Stereotype.

Composition, allowing one-fifth extra (see above)	16	16	0
Reading - - - - -	3	10	0
Press-work for five hundred copies, fourth extra	3	15	0
<hr/>			
Other expences and profits	24	1	0
	12	1	6
<hr/>			
Casting plates -	36	2	6
	50	0	0
<hr/>			
Twenty reams of paper	86	2	6
	30	0	0
<hr/>			
	116	2	6
Interest for six months	2	18	6
<hr/>			

Carry over 119 1 0
Z 2

	£	s.	d.
Brought forward - - -	119	1	0
Cost of the first five hundred, second, and of each subsequent five hundred, will be } 38 <i>l.</i> 5 <i>s.</i> 3 <i>d.</i> - - -	267	16	9
	<hr/>		
Common printing - - -	386	17	9
	336	4	6
Balance against stereotype, after four years	50	13	3
The next edition of four thousand copies } by common printing will cost as before }	336	4	6
Ditto on stereotype eight times 38 <i>l.</i> 5 <i>s.</i> 3 <i>d.</i>	306		
Balance in favour of stereotype in the } second edition - - - }	30		

Hence it appears, that it will require more than ten years to clear the expence of the plates only, and after that it will yield a profit of 30*l.* 2*s.* 6*d.* on every subsequent edition of 4000 copies.

From the foregoing estimate, and several others given by the same author, which are not more favourable to the new mode of printing, other advantages must be looked for than those which result from pecuniary savings; but new discoveries may render the process more economical than it is at present: thus, if the pages could be cast so true, that they might go to press, and be worked with the same ease and

expence as moveable types; and if a substitute could be found for oiling and brushing the pages so as not to wear the type, or increase the labour of the compositor, more decided advantages would result from the introduction of stereotype: such as the following.

1st. On books published in parts or numbers. Purchasers frequently take in the early parts and leave off, by which the sets become broken and uneven, and a great loss is incurred by the waste of paper. This might be prevented by stereotype, which so remarkably facilitates the perfecting any parts or numbers that are found deficient.

2dly. On new books of doubtful sale. The plan of casting plates would not involve an expence of more than sixpence for an octavo page, besides the metal, which will still retain its value. So that a hundred, or a less number of copies, might be struck off to ascertain the opinion of the public. If it did not sell, the loss on a work of 20 sheets would not be more than about 8*l.*, besides the composition; but if 500, or 750 copies were printed in the common way, and not sold, the loss would be from 30*l.* to 40*l.*

3dly. The principal advantage is unquestionably on stock books, whether bibles, prayer-books, or school-books, particularly works of arithmetic, and other branches of mathematics. These, by means of the stereotype, may be brought to perfect accuracy; and having once attained to that standard, may be kept so without the possibility of deviation: for this excellence, the public would not grudge even an extra price.

Still

STILL, the name of an apparatus used in distillation. See **DISTILLATION** and **LABORATORY**. See also **ALEMBIC**, **RETORT**, **WORM**, &c.

Dr. Lewis has contrived a still, adapted to his portable furnaces, which is sufficient for the purposes of an experimental laboratory. The body of the still is a wide copper pan; and, for distillation in a water-bath, another vessel of the same figure is received into it almost to the top, the

space between them being nearly filled with water. Both these vessels are of the same width at the mouth, and either may be used as a still equally with the other: either of them serves also, on other occasions, as an evaporating pan, a boiler for experiments in dyeing, and other like purposes.

All the parts are made of thin copper plate, and well tinned on the inside with pure tin. In consequence of their

thinness, they admit of some alteration of their figure about the edges, so that though they should not be perfectly round, they are readily accommodated to one another, and fit close: the juncture is easily made perfectly tight, by applying round it narrow slips of moistened bladder, which are more convenient than luting, as being readily stripped off when the operation is finished. A short pewter pipe, with a pewter stopper fitted to it, for returning the distilled liquor, or pouring fresh liquor occasionally into the still, without the trouble of unluting and separating the vessels, is soldered into the top of the head, which, in these kinds of instruments, is the most convenient place for it. For separating, by distillation, spirituous from watery liquors, or the rectification of spirit of wine, the head is raised, by inserting between it and the breast, a thin copper pipe about two feet long. A worm and refrigeratory are necessary, as for the common still; and a glass head is requisite for some uses, particularly for the distillation of vinegar, and such other liquors as would corrode a copper one, and impregnate themselves with the metal; in which case, the use of the metalline worm also is to be avoided, and the glass or stone-ware receiver joined to the pipe of the head. Lewis's Com. of Arts, p. 9, 10.

STILL-Bottoms, in the *Distillery*, a name given by the traders to what remains in the still, after the working of the wash into low wines.

These bottoms are procured in the greatest quantity from the malt wash, and are of so much value to the distiller in the fattening of hogs, &c. that he often finds them one of the most valuable articles of the business. They might also be put to other uses, such as the affording of a large proportion of an acid spirit, an oil, a fuel, and a fixed salt; and with some address, and good management, a vinegar and a tartar. Another very advantageous use of them, is the adding of them to the next brewing of the malt for more spirit: the increase of the produce from this is more than could easily be conceived. It also more readily disposes the new wash to ferment, and gives the spirit a vinosity that it cannot have without it; the proportion, in this case, can never exceed that of a fifth or sixth part of the whole quantity of the liquor employed. The liquor left behind in the still, after the rectifying of the low wines into proof-spirit, is also called by some by the name of still-bottoms; but this is little more than mere phlegm, or water impregnated with a few acid, and some oily parts, not worth separating, unless for curiosity. The liquor left in the still, after the rectifying of the proof-spirit into alcohol, is also of the same kind.

The bottoms of molasses spirits seem calculated for many uses. It is very probable that the vinegar-makers would find their account in trying them, and the strong and lasting yellow colour with which they tinge the hands may recom-

mend them to the dyers. A small proportion of them, added to the new treacle to be fermented, greatly promotes the operation, and increases the quantity of spirit.

The bottoms of the wine spirit, that is, the remainder after distilling the spirituous part from damaged wines, or wine-lees, may be brought to afford Mr. Boyle's acid spirit of wine, and that substance, called by Becher the *media substantia vini*. A parcel of tartar may also be procured in very great perfection; and the last remainder may be converted into excellent and genuine salt of tartar. The liquor may otherwise be serviceable in making vinegar and white lead. Shaw's Essay on Distillery.

STILL-House. The Dutch have much the advantage of us in the structure of their still-houses, and have every thing in great readiness and neatness. The general rules in building these houses should be these:

The first caution is to lay the floor aslope, not flat, where any wet work is to be performed: it should also be well flagged with broad stones, so that no wet be detained in the crevices, but all may run off, and be let out at the drains made at the bottom and sides.

The stills should be placed abreast on that side of the still-house to which the floor has its current. The largest stills in Holland, for their greatest works, are never of that monstrous size which are constructed in England, but much more manageable and convenient, as seldom containing more than six or eight hogheads; and with such stills a single hand will perform more business than with one of a much larger size. Fronting the stills, and adjoining to the back wall, should be a stage for holding the fermenting backs, and these being placed at a proper height, may empty themselves, by means of a cock and a canal, into the stills, which are thus charged with very little trouble.

Near this set of fermenting backs should be placed a pump or two, that may readily supply them with water by means of a trunk or canal, leading to each back. Under the pavement adjoining to the stills should be a kind of cellar, wherein to lodge the receivers, each of which should be furnished with its pump, to raise the low wines into the still for rectification; and through this cellar the refuse wash, or still-bottoms, should be discharged by means of a hose, or other contrivance. These are the principal things to be regarded in the erecting of a still-house for the original production of spirits; and if these rules are well observed, malt-spirit will be made with little more trouble than molasses; for by this means the business of brewing and cooling the wash, which, according to the method generally practised in England, takes up so much time and trouble, is entirely saved, fermentation is carried on to a much greater advantage, and the quantity of spirit increased. Shaw's Essay on Distillery.

Stocking-frame

STOCKING-FRAME, a most ingenious machine for weaving or knitting of stockings. To comprehend the action of this machine, which is extremely complicated, it is first necessary to have a perfect idea of the nature of the fabric which is produced by it: this is totally distinct from cloth woven by a loom, as the slightest inspection will shew; for instead of having two distinct systems of threads, like the warp and the weft, which are woven together, by crossing each other at right angles, the whole piece is composed of a single thread, united or looped together in a peculiar manner, which is called stocking-stitch, and sometimes chain-work.

This is best explained by the view in *fig. 1. Plate Stocking-frame*. A single thread is formed into a number of loops or waves, by arranging it over a number of parallel needles, as shewn at R: these are retained or kept in the form of loops or waves, by being drawn or looped through similar loops or waves formed by the thread of the preceding course of the work, S. The fabric thus formed by the union of a number of loops is easily unravelled, because the stability of the whole piece depends upon the ultimate fastening of the first end of the thread; and if this is undone, the loops formed by that end will open, and release the subsequent loops one at a time, until the whole is unravelled, and drawn out into the single thread from which it was made. In the same manner, if the thread in a stocking piece fails or breaks at any part, or drops a stitch, as it is called, it immediately produces a hole, and the extension of the hole can only be prevented by fastening the end. It should be observed, that there are many different fabrics of stocking-stitch for various kinds of ornamental hosiery, and as each requires a different kind of frame or machine to produce it, we should greatly exceed our limits to enter into a detailed description of them all. That species which we have represented in *fig. 1.* is the common stocking-stitch used for plain

hosiery, and is formed by the machine called the common stocking-frame, which is the ground-work of all the others.

Fig. 2. is a perspective view of a common stocking-frame, exhibiting as many of its parts as can be seen in a general view. The basis is a wooden frame, consisting of four pillars N, and various cross-pieces, called rafters: the two uppermost, M, are called caps: upon the top of these the small parts of the machine are situated, being sustained in a frame of wrought iron. The pieces which compose the iron frame are two sole-bars *w*, which are screwed down upon the wooden caps M, and at the ends have joints, *g*, to support the presser-bows G, G, of which we shall soon have occasion to speak. At the back are two vertical standards, V, called the back standards, which support the axis T. These standards are united by back cross-bars, which are clearly seen in the figure near V. There are likewise two front standards W, erected from the sole-bars *w*, *w*.

To give motion to this machine, the workman seats himself before it, upon a board or seat A, and puts the different parts of the machine in motion by his hands and feet: he applies his feet upon two treadles B, C, which have cords, *b*, *c*, ascending from them, and passing in opposite directions round a barrel or wheel, upon the axis of which is a large wheel, D, called the flur-wheel. By alternately pressing down one treadle, and allowing the other to rise, he can turn this wheel round in either direction at pleasure. The object of this movement will be described hereafter. There is likewise a third treadle, E, upon which he presses his foot, when he wishes to bring down what is called the presser-bar, marked F, the use of which will be afterwards explained. This bar is attached to two arms or levers G, which are moveable round the fixed centre pins or joints *g*. The ends of the levers are of a curved form; hence the pieces G are called

the *preffer-bows*. The connection with the treadle E is by a string or wire *e*, which ascends behind the machine, and is attached to the cross-bar H, which is extended from one of the *preffer-bows* to the other, and is cranked down, to avoid such parts of the machine as it would otherwise intercept in its motion. The return of the *preffer* and middle treadle, E, is produced by the re-action of the wooden spring I, which draws it up with two strings; but in some frames a counter-weight is used instead of the spring.

The weaver produces all the other movements by his hands: for this purpose, he applies them to the ends K, K, of the hand-bar, and he can then very conveniently press his thumbs upon the thumb-plates L, L. By drawing forward or lifting up the hand-bar K, and at the same time pressing upon the thumb-plates L, or relieving them, he gives the requisite motions to what is called the frame of *sinkers*, or simply the frame, because it contains the principal works of the machine. The thread of which the stocking is to be made is kept upon a bobbin M, stuck upon a pin in the front upright, N, of the frame, and the thread from this is carried upon the needles; and when it is woven into the stocking piece by the action of the needles and *sinkers*, the piece hangs down at S, and is received upon a small roller fixed in an iron frame *p*, called the web, which is made sufficiently heavy to stretch the piece to a moderate tension.

As an introduction to a description of the whole machine, it will be proper to give the reader an idea of those parts which operate upon the thread, and of the motions which are given to them to produce the loops or meshes. These parts are the needles, the frame of *sinkers*, and the *preffer*-bar: the needles are stationary, the rest moveable.

Fig. 1. represents what are called the needles: these are made of iron-wire, of the shape represented, and are hooked or barbed at the ends, the returned points of the hooks or barbs being made very delicate. There is a small cavity or groove punched or sunk in the stem of the needle, immediately beneath the barb, of sufficient depth to receive the point, when an adequate pressure is applied upon the hook to bend the barb down. The barb then becomes a closed eye; and if a thread is looped over the wire or stem of the needle, and drawn forwards while the barb is thus closed, it will draw over the barb of the needle, and come off at the end of it: but if the thread is drawn forwards whilst the barb is open, it will be caught under the hook, and be thus detained, as shewn at R. This circumstance must be particularly attended to, as the principal action of the machine depends upon it. The depression of the barbs of the needles is produced by the edge of the *preffer*-bar F, which is extended horizontally over the whole length of the needles, and actuated by pressing the foot on the middle treadle, as before explained.

Between every two adjacent needles, 1, 1, a thin plate of steel, 2, 3, is placed: these plates are called *sinkers*; they are formed to a particular shape (as shewn in fig. 4.), and are capable of being elevated or depressed, and also of being drawn backwards or forwards between the needles. These motions are given by the hands of the weaver, as the hand-bar K, which he holds, is part of the frame containing the jacks and *sinkers*. The *sinker*-frame consists of the hand-bar K K (fig. 2 or 4.), extending across it at the bottom; the hanging cheeks O, O, which form the upright sides of the frame; and the upper bar P, which is called the *sinker*-bar, because the *sinkers* are fixed to it, being united several together in pieces of lead each an inch wide, which are cast round the ends of the *sinkers*, and fastened by screws to the bar P.

To allow the frame of *sinkers* to have the motions of

which we have spoken, it is suspended by joints at the top of the hanging-cheeks, called the top joints: these joints are formed at the ends of the top arms, Q, Q, which are two horizontal levers fixed to an axis T, called the spindle-bar: the extremities of this turn on pivots, supported by the upper ends of iron uprights V, called the back standards. By the motion of the spindle-bar upon its centres, the frame of *sinkers* can rise and fall, and the quantity of this motion is limited by stop-screws applied to the vertical standards W. To draw the *sinkers* forward between the needles, the *sinker*-frame can be inclined upon the top joints of the hanging-cheeks, by drawing forwards the hand-bar K. From the middle of the spindle-bar, T, a short lever projects, which is borne upwards by a spring, Y, called the main-spring: this is supported by a piece which projects from the fixed cross-bar of the frame, and is of sufficient force to bear the frame of *sinkers* upward, and give the top arms, Q, Q, a tendency to rest always against the upper stop-screws, X, of the standards W.

The hooked part or nips *f* (fig. 4.) of the *sinkers*, are for the purpose of forming loops in the thread between the needles. To effect this, the nips, *f*, of the jacks and *sinkers* are raised above the level of the needles, as in fig. 4, and the thread is extended across all the needles, immediately beneath the nips. If then the jacks and *sinkers* are all pressed down between the needles, it is evident that the nips of the *sinkers* must carry the thread down before them, and form it into loops hanging down between each needle, as shewn at X. This, then, is the principal office of the *sinkers*: but to perform the operation of *sinking* in the manner now described, by depressing the whole number at once, would not be practicable; because, as a greater length of thread is required when it is depressed into loops, than when it lies straight across the needles, it would require to draw the thread all at once from the bobbin M (fig. 2.), in sufficient quantity to make up the difference; to do which, the thread must slide or draw beneath between the nips and the needles, which it could not do, on account of the friction.

The contrivance to render this depression or looping down of the thread between each needle practicable is very ingenious. The row of *sinkers* shewn in fig. 4. is composed of two kinds, called *jack-sinkers* and *lead-sinkers*, which are very different in their movements, although we have hitherto spoken of them as one. The *lead-sinkers* are all those of which we have spoken as being fastened to one bar P, called the *sinker*-bar, which is part of the *sinker*-frame, and which the workman moves by his hands: on this account, the *lead-sinkers* all move together; they are one half of the whole number, and are disposed between every other needle, so that the space between each *lead-sinker* has two needles in it. The *jack-sinkers* are made of the same form as the *lead-sinkers*, one being placed between each of the two needles contained between every *lead-sinker*; therefore the *lead-sinkers* and *jack-sinkers* are disposed alternately to form a row, and a needle is placed in every space in the whole row. Each *jack-sinker* is supported by a small lever, *h*, *i*, (fig. 3.) called a *jack*, freely movable on a centre-pin: the opposite end *i*, or tail of each *jack*, is pressed by a spring *k*, which has a notch or indentation at a particular place; and when the *jack-sinker* is elevated, so that its nip, *f*, is above the level of the needles 1, ready to receive the thread, the end of the tail, *i*, is received in the notch of the spring *k*, which retains it in that position; but at the same time a slight force applied beneath the tail, *i*, of the *jack* to lift it up will depress the nip, *f*, of the *jack-sinker*, 3, between the needles. It is to be understood, that all the jacks, *h*, *i*, are arranged in a row, and move upon one wire, which is a common centre of

motion; but the motion is given to them one at a time, beginning at one end of the row, and proceeding one by one to the other. To effect this, a straight iron bar, or ruler *l*, called the slur-bar, is extended beneath all the jacks, and upon this a piece of metal, *m*, called the slur, travels, with rollers to reduce the friction: it is drawn by a line extended from each side, and conducted over a pulley *n*, at each end of the bar *l*, to be carried round the slur-wheel *D*, *fig. 2*. We have before explained how an alternate motion is given to this wheel, by the action of the two feet upon the two treadles *B, C*: it is plain by this connection, that the slur, *m*, can be made to travel from one end of the slur-bar, *l*, to the other, and in so doing, that it will elevate the tails, *i*, of all the jacks, *i, b*, beneath which it passes, and produce a corresponding depression of the jack-sinkers, *3*, between the needles. After the slur has passed, the jacks retain the position given to them by the pressure of the springs *k*.

The operation of linking or forming the loops between the needles is thus conducted: the nips of all the sinkers are raised above the needles, as in *fig. 4*; the thread is then extended lightly across the stems of the needles, beneath the nips *f*. By pressing on one of the treadles, *B* or *C*, the slur-wheel *D* is made to turn round, and this, by the slur-line, draws the slur, *m*, from one end of the slur-bar, *l*, to the other. In its passage it encounters the tails, *i*, of the jack, and lifts them up one by one, which at the same time depresses the corresponding jack-sinker *3*; and its nip, *f*, links the thread between the needles, and forms a loop. As these loops are formed successively, the thread draws easily beneath the nip to produce each single loop, and the workman allows the threads to draw off from the bobbin, *M*, through his fingers, as fast as it is required. When all the jack-sinkers are depressed, a loop of the thread will be formed between every other pair of needles. The workman then depresses the lead-sinkers, *4*, by pulling down the hand-bar *K*, and their nips carry down the thread between the remaining needles in loops, in the intermediate spaces between the former loops: in doing this, he causes the jack-sinkers, *4*, to rise up, as much as he depresses the lead-sinkers *3*; because it should have been mentioned before, that the first loops formed by the jack-sinkers were double the depth intended, although only half the number: by this means they contained the proper quantity of thread to form the whole number of loops; *viz.* one between every two adjacent needles.

The jack-sinkers are caused to rise up by means of the locker-bar, *p*, extending over all their tails *i*. Each end of this bar is screwed to a lever, *g*, called a locker, which moves upon the same centre as the jacks, and the front ends of these levers are made with inclined ends, so as to be lifted up by wedges fixed at the back of the thumb-plates, *L*, which move on joints fixed to the sinker-bar, and hang down in a convenient situation to be acted upon by the thumbs of each hand, when holding the ends of the hand-bar *K*. The weaver, therefore, presses back the two thumb-plates *L*, at the same time that he depresses the hand-bar, *K*, of the frame containing the lead-sinkers; by which means he produces the ascent of the jack-sinkers, in an equal degree to the descent of the lead-sinkers, until the nips of the two arrange exactly in one line, which position is determined by proper stops attached to the sinker-frame. By this means, a complete row of loops is formed, one loop between each needle.

These loops are now to be carried backwards upon the needles, into the position of *S*, *fig. 1*, so as to occupy the arch or opening, *s*, of the sinkers, which open part is made purposely to admit the loops last made to remain upon the stems of the needles, quite detached from the action of the

sinkers, which are at liberty to form a new course of loops by the nips, *f*, of their points *t*.

If we suppose the frame has been before at work, the loops last formed, which hang upon the stems of the needles, will not be a single thread, but the loops at the upper part of the work *S*, *fig. 1*: it is only when the frame first begins to work that the loops will be a detached thread, as we have just described.

But it remains to shew how the loops are put back upon the needles: this is done by merely lifting up the hand-bar *K*, till the points, *t*, of the sinkers rise above the needles: the hand-bar is then drawn forwards a little, to advance the sinkers so much, that the points *t*, which were behind the loops of thread upon the needles, will now come before them, and then the hands are depressed, to insert the points, *t*, between the needles again before the threads; and by pushing back the hand-bar, the points, *t*, carry back the work upon the stems of the needles, so that it will be situated in the arch, or opening, *s*, of the sinkers.

When the sinkers advance or recede, they must all move together both the lead-sinkers and jack-sinkers, as if they were one. It is clear that there is no impediment to the moving forwards of the lead-sinkers, because they are at liberty to incline or swing forwards upon the joints at the tops of the hanging-cheeks, *O, O*, which suspend the frame containing them: but for the jack-sinkers to advance at the same time, it is necessary to bring forward the jacks, and their centre of motion, together with the springs and slur-bar. To admit of this motion, all those parts are framed upon a strong bar called the camel; and upon this is placed four wheels, which run upon the sole-bars, so as to become a carriage. To communicate motion to this carriage, a link is jointed to a piece at each end, marked *r*, *fig. 2* or *4*, which is screwed to the sinker-bar *P*, just within the thumb-plates *L*. These links are jointed at the other ends to the common centre of motion of the jacks. The joints of the pieces, *r*, are so adjusted, that they will exactly line with the joints which unite the jacks and jack-sinkers together; and the links are the same length between the centres as the jacks, for which reason they are called half-jacks.

By means of this connection, the carriage, with all its appendages, *viz.* the jacks, with their springs and the slur-bar, are drawn forwards at the same time that the sinker-frame is drawn forwards, by pulling the hand-bar *K*; or, by a contrary movement, the loops of threads which were last formed upon the needles, will be carried back from the hooks or beards of the needles upon their stems, as shewn at *S*, *fig. 1*, so as to be in the arch, *s*, of the sinkers, as before described.

The first row of loops being thus disposed of, the frame of sinkers is restored to its former position, and a second row is formed upon the stems of the needles by a repetition of the same process, *viz.* extending the thread across the needles beneath the nips, *f*, of the sinkers; moving the slur by the two outside treadles *B, C*, which depresses all the jack-sinkers, and makes a loop of double depth between every other pair of needles: this is called drawing the jacks: next pressing on the thumb-plates *L*, and depressing the hand-bar, *K*, at the same time, which elevates the jack-sinkers, and depresses the lead-sinkers by one movement, and produces a loop of thread between every two adjacent needles. Another complete row of loops is now formed upon the stems of the needles; and this row is to be brought forwards, so as to be under the beards or hooks of the needles, in the manner shewn by *R*, *fig. 1*. This is produced by simply drawing forwards the hand-bar *K*,

which advances all the sinkers together, and their points, *t*, push forwards the thread till it comes into the beards, and these prevent it from coming off the needles.

The next operation is lifting up the hand-bar and frame of sinkers as much as will raise their points, *t*, quite clear up above the needles between which they were situated, and applying the foot on the upper treadle *E*, to bring down the pressing-bar, *F*, upon the beards of the needles, to close them up, and while so closed, they hold the loops of thread at *R*, as if they were looped through the eyes of as many needles. The upper loops of the works which are at *S*, *fig. 1*, upon the stems of the needles, in the arch, *r*, of the sinkers, are next brought forward upon the needles, by drawing forwards the frame of sinkers; but in advancing these loops, draw over the closed beards of the needles, and consequently over the last-formed hoops, which remain under the beards, in the position shewn at *R*, *fig. 1*; or, in other words, the loops last formed, and resting under the beards at *R*, *fig. 1*, are drawn through the loops of the upper or last course of the finished work which remained upon the stems of the needles, as represented at *S*. By this means, the loops of what was the upper or last course of the finished work, become secured from opening or unravelling, and the loops under the beards now become the last or upper course of the work, and are preserved from unravelling by the needles, one of which passes through each loop; and these loops will not be drawn off from the needles until there is another row of loops prepared, and reserved under the beards of the needles, ready to be drawn through them. When the piece of work is finished, and taken off from the frame, the last made row of loops must be secured by running a thread through them, or other means, or they would draw through the preceding loops, and release them, which in like manner would release their predecessors, and so the whole piece would unravel.

The motion of the frame of sinkers, which produces the advance of the sinkers towards the points of the needles, or their recession towards the stem, takes place upon the centres, called the top joints *oo*, and the wheels of the carriage, as before mentioned. The quantity of motion is limited by a piece, *fig. 7*, called the arch, which is fixed fast against the inside of the wood-frame *N*, *fig. 2*: a part of the hanging-cheeks *O, O*, of the frame of sinkers descends with a projecting part to act round this arch, which, at the same time that it limits the quantity of motion, prevents the motion being made, except in a proper succession, to produce the effects before described. Thus, when the hook is beneath the arch, the points, *t*, of the sinkers will be beneath the level of the needles, and then the frame of sinkers cannot be raised up without first moving the lower part of the frame either forwards or backwards. In the same manner, when the hook is above the arch, the sinkers cannot be depressed till they are moved. When the thread is first extended across the needles, in order to be sunk into loops, the frame is said to be over the arch, that is, the hook is at the back, or on the farther side of the arch, and by applying thereto, the sinkers are guided in their sinking, that is, when they descend, they depress the thread to form the loop. When this sinking has taken place, the sinker-frame will be at its lowest position, and the top arms, *Q*, will rest upon the lower stop-screw of the standards *W*. When the sinkers are brought forwards, to draw the loops from the stems of the needles into their beards or points, the hook of the frame moves along the under side of the arch, and this prevents the points lifting up, while the lower stop prevents them from sinking down: but when the sinkers are brought sufficiently forwards, the frame is lifted or thrown up by the

main-spring, the hook following the curvature of the arch, until the points are completely above the needles, or the frame has reached the upper stop. The sinkers are then brought forwards upon their centre of motion, while the presser is drawn down to close the beards of the needles and draw the loops over them; in doing which, the hook quits the arch, and the frame comes forwards without any guide, the same being unnecessary, because the elevation of the sinkers is determined by the upper stop, against which the frame rises by the action of its main-spring; and the proper degree for the advance of the sinkers is determined by the drawing forwards of the frame with sufficient force to draw the loops of the work tight: this force the workman must regulate by habit, so as make his work close.

In returning the frame of sinkers, in order to put back the work upon the stems of the needles, so as to be out of the way while a new row of loops is made, the hook, *g*, must be carried back beneath the arch, which will keep down the points of the sinkers, so as to prevent them from rising above the needles, as they would then quit the work they are intended to drive back upon the needles.

By the operation which we have described, one course of the work is formed; but, to render it more clear, we will continue the description, in a few words, of the working of another course. Preparatory to working it, the loops of the last course of the work, and by which the work is suspended from the needles, must be pushed back upon the stems of the needles to the position *S*, *fig. 1*, so as to come into the arched or open part *r*, *fig. 4*, of the sinkers: this is done by depressing the sinkers low enough for their point, *t*, to enter between the needles, and then pushing back the hand-bar and frame of the sinkers to carry back the work upon the stems of the needles. This is the situation in which we suppose the frame, when the operation commences; and the frame is over the arch.

The first movement is the gathering of thread. The thread laid over is lightly extended across the needles, beneath the nips, *f*, of the sinkers; and by pressing the sur-treadle *BC*, the jack-sinkers are depressed one by one, so as to form double loops. This is called drawing the jacks.

The second movement is sinking. This is done by drawing down the hand-bar *K*, and bearing upon the thumb-plates, *L*, at the same time: the whole row of lead-sinkers is thus depressed, whilst the jack-sinkers rise, and the thread is carried down into a loop between every two needles.

The third movement is to bring the frame forwards under the arch. This is done by drawing the hand-bar forwards, and the row of loops just made is brought under the beards of the needles.

The fourth movement is to bring the work forwards from the stem of the needles. To do this, the sinker-frame is lifted up, by elevating the hand-bar *K*, so that the point, *t*, of the sinkers will be quite drawn out above the needles; and in this situation, the hand-bar and sinker-frame being brought forwards, the breast or curved part of the arch, *s*, of the sinker will bring forwards the piece of work which hangs upon the stems of the needles, by its loops last made.

The fifth movement is closing the work, or drawing the loops last made, through the finished loops of the work. The presser-treadle *E*, being borne upon at the same moment, will bring down the presser, and it will bear upon the beards, and close them, while the loops are drawn forwards; consequently the loops of the old work will be drawn over the beards, and quite off from the needles: this draws the loops thereof over the loops last made, which re-

main in the beards of the needles. To draw the work tight, the hand bar, K, is drawn forwards two or three times with a slight jerk, so as to extend all the loops to their fullest quantity, and make the loops of the work unite closely.

The course is now finished; but as a preparation for making another course, the work must be carried back upon the stems of the needles into the situation of S, *fig. 1*. This is the sixth and last movement. To put back work, the frame is pulled down to bring the points of the sinkers below the level of the needles; and in this position, by pressing back the hand-bar, and all the sinkers together, the points, *t*, will enter between the ends of the needles, and carry back the loops of the work upon the stems of the needles, where it will remain in the arches of the sinkers, so as to be detached from them, and out of the way, while a new set of loops is formed by the nips of the points of the sinkers; and then the loops of the old work are to be drawn over those last made.

The movements are then repeated: 1st, gathering the thread upon the needles, and depressing it into large loops between every two needles, by the motion of the slur; 2d, sinking, to make the loops between all the needles; 3d, bringing the thread under the beards of the needles; 4th, bringing the work forwards from the stems of the needles towards the beards; 5th, closing the beards by the pressure of the presser-bar, and drawing the work over the beards; and, 6th, putting the work back on the needles, ready for working another course.

The operation of the machine proceeds in the manner described; and as fast as the courses are completed, the work descends lower, and hangs down in a web from the needles. When the piece is of a considerable length, it is rolled upon a roller, in an iron frame *p*, called the web, and the weight of the frame is sufficient to keep the piece to a proper tension. The roller in the web can be turned round occasionally to wind up the piece, and is retained by a ratchet-wheel and click.

Having given an idea of the manner of the operation of this curious machine, it only remains to explain the adjustments with which it is provided, in order to make it work correctly.

The fineness of the work depends on the number of loops which the thread will make in any given length, and this will be equal to the number of needles and sinkers in the same space. The number of needles in an inch is called the gauge of the frame, and they vary from 15 to 40, which latter are used for the finest stockings. The gauge of a frame cannot be altered when it is once made, and the work which it will produce must always be of the same degree of fineness, although it may be made a little more dense or more slight by drawing the loops very close,

or by allowing a greater quantity of thread, and making the loops longer. This circumstance will evidently depend upon the depth to which the nips of the sinkers descend between the needles, when they carry down the thread into loops. To regulate this depth, the needle-bar, or that piece which sustains the leads containing the row of needles, is made to rise or fall a slight quantity, by means of two long adjusting screws, the heads of which are made with notches, and springs fall into them to keep the screws from turning back: these heads are called the star, and the notches nicks: one is marked 9, in *figs. 2* and 3.

The motion allowed to the frame of sinkers is limited, as before-mentioned, by stops projecting from the two upright standards, W; and through these stops, stop-screws, *x*, are fitted, to regulate the degree of ascent and descent. The main-spring, *y*, is made of sufficient strength to lift the weight of the frame of sinkers, and make them always rise up as high as the upper stop-screws will permit.

The manner of making different parts of the stocking-frame is worthy of notice. The needles are made of iron-wire, of a proper degree of fineness: it must be of good quality, as that which is liable to split or splinter, either in filing, punching, or bending, is totally unfit for the purpose. The wire is cut to lengths, and annealed or softened in a box of charcoal, in which they are heated to redness, and suffered to cool gradually. The needles are next punched with the small cavity which is necessary to receive the point of the beard: this is done by a simple screw-press. The point of the needle is next formed by the file and burnisher, and the hooks are then bent to form the barb: next the needles are flattened, each with a blow of the hammer. To fasten these needles together, and fix them in the machine, they are placed parallel to each other in a mould or frame, and tin or pewter poured into the mould, round the flattened ends of the stems. The piece of lead or pewter is just an inch in width, and the number of needles which it will contain, gives the denomination to the gauge of the frame. These leads of needles are fastened to the needle-bar by a screw through each. The lead-sinkers are made of steel-plates, which are put together by casting lead round them at the upper ends, in the same manner as the needles. The rack or piece, which contains the centre of the jacks, is called the comb, because it is composed of a number of small plates, fixed into a bar by casting them with lead or tin.

The stocking-frame has undergone very few alterations since its first invention, a circumstance highly creditable to the genius of the inventor. A stocking-frame for weaving the tartan plaid hose which is worn in Scotland, is described in the Society of Arts Transactions, vol. xxix. p. 84: it contains some additions invented by Mr. John Robertson.

STOCKING FRAME

Fig 1

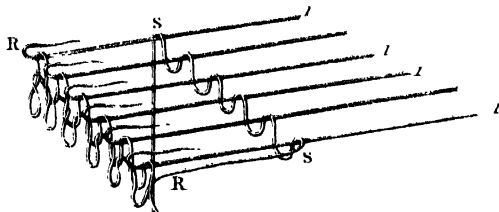


Fig 7

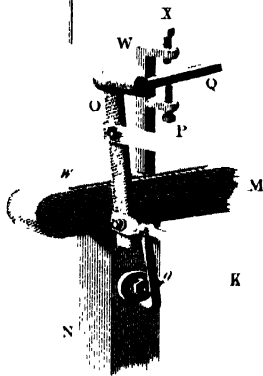


Fig 1

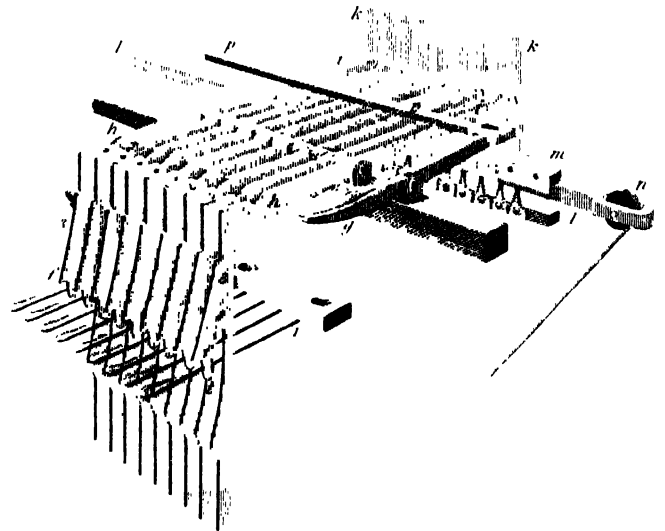
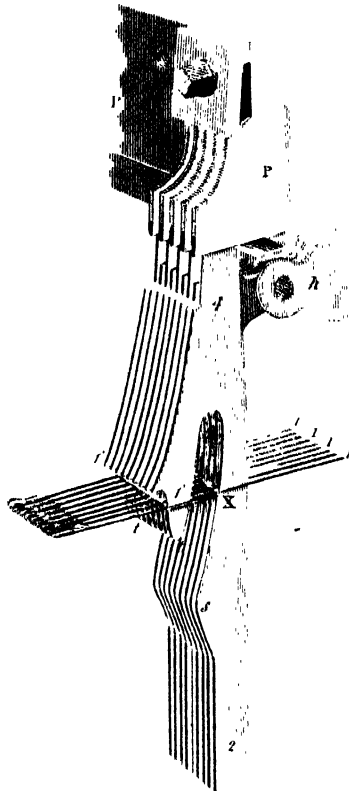
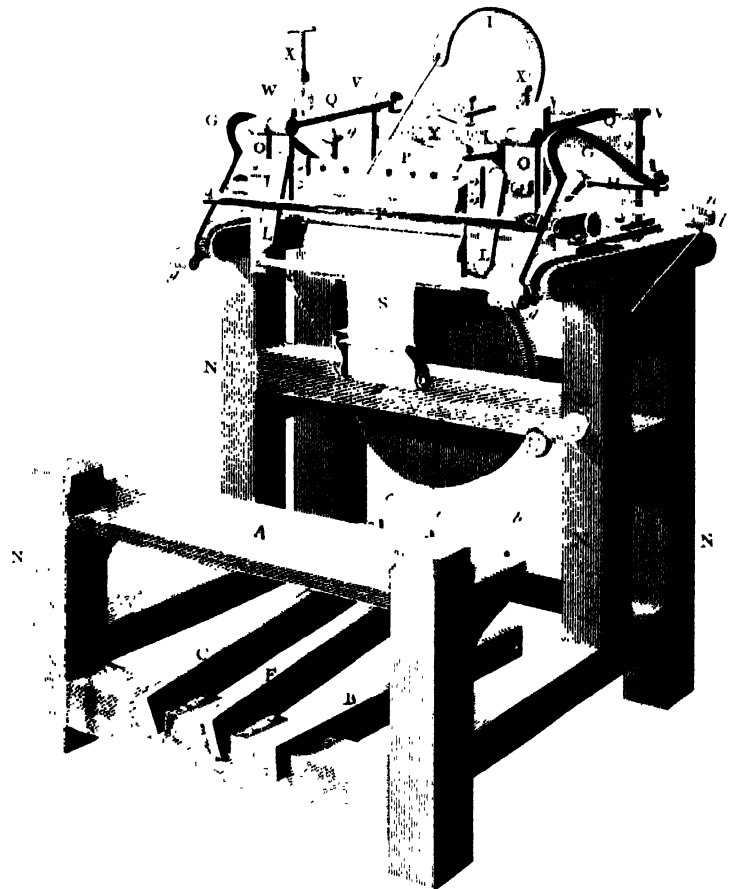


Fig 2.



Stove

STOVE, in *Building*, a hot-house or room. The term stove is also used more restrictedly for a place in which fire is made, and by means of which heat is communicated to a room or building. See CHIMNEY.

Stoves should, in propriety, be distinguished from fire-places, from the fire being inclosed within the stove, and giving out its heat through the substance of the materials of which the stove is composed, to the air in the apartment; and in many stoves there are ingenious con-

trivances, to make a great quantity of air pass in contact with the heated surface of the stove, and be thus heated before passing off into the apartment. Fire-places, on the contrary, have the fire as open and as much exposed as possible, consistently with the carrying off of the smoke, in order that it may throw out radiant heat into the apartment. This distinction is not sufficiently attended to in common language.

In modern fire-places, every care is taken that the air of the room may be heated; but it does not appear, from the construction of their fire-hearths, that our forefathers had any idea of warming the air of a room to fit in. All they proposed was to have a place to make a fire in, by the radiating heat of which they could warm themselves when cold.

The ancients are supposed to have used stoves, in which the fire was not seen; but on inquiring into the progress of the art of warming apartments economically, few traces remain of the manner in which the ancients warmed their habitations. It is imagined they lighted the fire in a large tube in the middle of a room, of which the roof was open, and that the other apartments were warmed by portable braziers. In Seneca's time, they began to construct tubes in the walls, to convey the heat into the upper apartments; the fire-places being still placed below. It appears, however, that this was the origin of flues for smoke, and even of stoves; the situation and proportions of which have successively undergone an infinity of changes, according to the localities, the wants of the inhabitants, or the style of the decorations.

The ancients had the custom of heating apartments by fires placed under arches or vaults; but this was confined to palaces, and other edifices, where magnificence was augmented by prodigality; and the vestiges that have been discovered among ancient ruins, sufficiently point out this as their destination. In digging, some years ago, for foundations in the city of Autun, one of these ovens was discovered under a mosaic pavement, with chimnies at each extremity.

The northern Chinese have a method of warming their ground-floor, which resembles the ancient plan just mentioned. The floors are made of tiles a foot square, and two inches thick; their corners being supported by bricks set on end, that are a foot long, and four inches square: the tiles, too, join into each other, by ridges and hollows along their sides. This forms a hollow under the whole floor, which on one side of the house has an opening into the air, where a fire is made; and it has a funnel rising from the other side to carry off the smoke. The fuel is a sulphurous pit-coal, the smell of which in the room is thus avoided, while the floor, and of course the room, are well warmed. But as the under-side of the floor must grow foul with soot, (and a thick coat of soot prevents much of the direct application of the hot air to the tiles,) Dr. Franklin suggests that burning the smoke, by obliging it to descend through the red coals, would, in this construction, be very advantageous; as more heat would be given by the flame than by the smoke, and the floor, thereby being kept free from soot, would be more heated with less fire. A different kind of stove used in China, and called *kang*, is briefly described under that article.

Francis Kellar of Frankfort, whose work, entitled "Epargne-bois," &c. (the Wood-saver, &c.), appeared, in French, in 1619, is the oldest writer who deserves to be quoted, as having proposed any useful ideas on the subject of stoves. He formed eight chambers, one above another, through which the smoke was to pass before it entered the chimney. He also brought air directly from without into the ash-pan, to feed the fire; and there was another aperture to draw air from the apartment for the same purpose.

Savot, in his "Architecture Française des Batimens particuliers," i. e. Architecture of private Houses, printed in 1625, gave some advice relative to the best method of constructing chimnies, but with scarcely any other object than to prevent their smoking.

M. Daleme, in 1686, suggested the first idea of a stove without smoke, which he called *furnus acapnos*. Here the smoke is forced to descend into the fire-place, where it is consumed. Dr. Franklin, who afterwards executed a very complete stove on that principle, still spoke of it, in 1773, as a mere curiosity or philosophical experiment, as it required too much attention to be managed by common servants.

This machine consisted of a tube of iron-plate, such as is used for the flue of a German stove. This tube was bent at right angles, and the part which was horizontal was about two feet in length, and joined to the rest of the tube, which ascended vertically. At the opposite end of the horizontal tube the furnace was made: it consisted of a cylindrical tube of plate-iron erected upon the horizontal tube near the end, and provided with a grating, upon which the fuel was placed; and the grate prevented the fuel falling down into the horizontal tube. To light this stove, some clear burning charcoal was put into the large short tube or furnace, and supported on the grate. As soon as the tubes grew warm, the air within them would ascend in the perpendicular tube or chimney, and go out at the top of it: fresh air must enter into the horizontal tube through the furnace. In this course it must descend through the burning fuel, and becoming heated by the burning coals, through which it has passed, would rise more forcibly in the longer tube, in proportion to its degree of heat, or rarefaction, and the length of that tube. Such a machine is a kind of inverted siphon; and as the greater weight of water in the longer leg of the common siphon, in descending, is accompanied by an ascent of the same fluid in the shorter; so in this inverted siphon, the greater quantity of levity of air in the longer leg, in rising, is accompanied by the descent of air in the shorter. The things to be burned being laid on the hot coals contained in the furnace, the smoke must descend through those coals, and be converted into flame, which, after destroying the offensive smell, comes out at the end of the longer tube, as mere heated transparent gas or vapour.

Whoever would repeat this experiment with success, must take care that the part of the short tube is quite full of burning coals, so that no part of the smoke may descend and pass by them, without going through them, and being converted into flame; and that the longer tube is so heated, that the current of ascending hot air will be established in it, before the things to be burnt are laid on the coals; otherwise there will be disappointment.

It does not appear, either in the Memoirs of the Academy of Sciences, or Philosophical Transactions of the English Royal Society, that any improvement was ever made of this ingenious experiment, by applying it to useful purposes; but there is a German book, entitled "Vulcanus Famulans," by Joh. George Leutmann, P.D., printed at Wirtemberg in 1723, which describes, among a great variety of other stoves for warming of rooms, one which seems to have been formed on the same principle. It was probably taken from the hint thereby given, though M. Daleme's experiment is not mentioned; for the construction is as nearly as possible the same, except in the proportion of the parts; the furnace being made in the form of a basin or vase, having the grate in the bottom of it.

Gauger, author of "La Mécanique du Feu," &c. printed at Paris in 1709, was the person to whom we are indebted for the first and most complete system of experiments on the circulation of heat, by means of air-holes affording warm air; as also the manner of making one fire warm several rooms, and to send off the heat in elliptic

curves. We there find a description of a chimney, with the back, the hearth, and the jambs, of hollow iron, to heat the air that is to enter the room. But it does not appear that this work produced much effect at the time: the most important truths lie concealed in books, till some pressing interest awakens the attention of mankind to their utility.

Dr. Franklin, in 1745, published an account of the new stoves of Pennsylvania; the advantages of which he compares with those of the stoves of Germany and Holland, and the chimney of Gauger. A description and drawing of this stove are given in our article *FIRE-Place*.

In 1785, Dr. Franklin published the description of another stove, which has the flame reversed; that is, it passes downwards through the fuel. The appearance of this stove is that of a vase of cast-iron, with its pedestal; and this is mounted upon the top or lid of an air-box, standing upon the hearth of the fire-place, and built close in a niche in the stone-work: but the vase being wholly detached from the back of the niche, has a very neat appearance. The top of the vase turns back upon a hinge, so as to open like a lid, to put in the fuel; and the opening is covered by a brass frame, which allows the air to enter. The bottom of the vase has in it an opening, of about two inches diameter, which leads through the stem or foot of the vase into a hollow iron box, forming the pedestal. At the bottom of this pedestal is a grating in the lid or top of the air-box, upon which the vase stands. The air-box is divided by four partitions, between which the smoke passes and repasses horizontally in a waving direction, until it escapes into the chimney. Thus the smoke and flame, immediately after it has descended through the grate in the top of the air-box, passes backwards towards the chimney between the two middle partitions; but as it cannot enter into the chimney at that part, it turns round the ends of those partitions, and returns in two currents towards the front of the box; then returns again round the end of other partitions, and goes back into the chimney, which is behind, or rather at the sides of the niche in which the vase stands. The front plate of the air-box is made to slide in a groove, in two pieces, which meet together in the front like folding-doors; and these pieces being slid back, expose the spaces between the partitions, which, as before mentioned, act as winding flues for the smoke to circulate in, and give out its heat through the metal of the air-box. In the space between the two middle partitions, and into which the smoke first descends, a drawer is fitted to receive the ashes or cinders, which may fall through the grate in the top of the air-box; and it can be readily withdrawn, to clear it out.

There is likewise a small grate at the lower part of the vase, upon which the fuel contained in the vase will rest. When this fuel is lighted, the flame and smoke will draw downward, and, descending through the grate, will pass through the hole in the bottom of the vase into the hollow pedestal, and through the grate in the top of the air-box: it then passes horizontally in the space between the two middle partitions of the air-box, and proceeds in the same direction towards the back of the chimney; there dividing, one part of it turns to the right, and passes round the farther end of the middle partition; then coming forwards, it turns round the near end of the outside partition; then moving backwards, it arrives at the opening into the bottom of one of the upright corner funnels behind the niche, through which it ascends into the chimney, thus heating that half of the box and that side of the niche. The other part of the divided flame passes to the left, round the far end of the middle partition, round the near end of the outside partition,

and so into and up the other corner funnel; thus heating the other half of the box, and the other side of the niche. The vase itself, and the box, will also be very hot; and the air surrounding them being heated, and rising, as it cannot get into the chimney, it spreads in the room: colder air succeeding, is warmed in its turn, rises and spreads, till by the continual circulation the whole is warmed.

If there is occasion to make the fire when the chimney does not draw, it must not be begun in the vase, but in one or more of the passages of the lower air-box; first withdrawing the sliding front of the air-box, and covering the mouth of the vase. After the chimney has drawn some time with the fire thus low, and begins to be a little warm, those passages may be closed, and another fire kindled in the hollow pedestal, leaving its sliding shutter a little open; and when it is found that the chimney, being warmed, draws forcibly, that passage may be shut, and the vase opened, to make the fire there, as above directed. The chimney, well warmed by the first day's fire, will continue to draw constantly all winter, if the fire is made daily.

In the management of this stove, there are certain precautions to be observed, at first with attention, till they become habitual. To avoid the inconvenience of smoke, the grate must be cleared before beginning to light a fire. If it is found clogged with cinders and ashes, the grate must be lifted up with the tongs, to let them fall upon the grate in the top of the air-box: the ashes will go through it into the drawer, and the cinders may be raked off through a sliding door in the pedestal, and returned into the vase, when they are to be burnt. Care must be taken that all the sliding-plates are in their places, and closely shut, that no air may enter the stove but through the round opening at the top of the vase; and to avoid the inconvenience of dust from the ashes, let the ash-drawer be taken out of the room to be emptied. The passages should be cleaned or raked out, when the draught of the air is strong inwards; and the ashes must be put carefully into the ash-box, whilst it remains in its place.

If it is required to prevent the fire burning in the absence of the proprietor, it may be done by removing the brass frame from the top of the vase, and covering the passage or opening into the top of the vase with a round tin-plate, which will prevent the entry of more air than barely sufficient to keep a few of the coals alive. When the fire is wanted, though some hours afterwards, by taking off the tin-plate, and admitting the air, the fire will soon be recovered.

The effect of this machine, well managed, is to burn not only the coals, but all the smoke of them; so that while the fire is burning, if the top of the chimney is observed, no smoke will be seen issuing, nor any thing but clear warm air, which, as usual, makes the bodies seen through it appear waving.

But it must not be imagined from this, that it can be a cure for bad or smoky chimnies, much less that, as it burns the smoke, it may be used in a room that has no chimney. It is only by the help of a good chimney, and the higher the better, that it produces its effect at all; and though a flue of plate-iron sufficiently high might be raised in a very lofty room, the management to prevent all disagreeable vapour would be too nice for common practice, and small errors would have unpleasing consequences.

It is certain that clean iron yields no offensive smell, when heated: whatever smell of that kind is perceived where there are iron stoves, proceeds, therefore, from some foulness burning or fuming on their surface; they should, therefore, never be spit upon, or greased, nor should any

dust be suffered to lie upon them. But as the greatest care will not always prevent these things, it is well once a week to wash the stove with soap-lees and a brush, rinsing it with clean water.

The advantages of this reversed flame in stoves are very considerable. The chimney does not grow foul, nor ever need sweeping; for as no smoke enters it, so no foot can form in it.

The air heated over common fires instantly quits the room, and goes up the chimney with the smoke; but, in the stove, it is obliged to descend in flame, and pass through the long winding horizontal passages, communicating its heat to a body of iron-plate, which, having thus time to receive the heat, communicates the same to the air of the room, and thereby warms it to a greater degree.

The whole of the fuel is consumed by being turned into flame, and the benefit of its heat is obtained; whereas, in common chimnies, a great part goes away in smoke, which may be seen as it rises, but it affords no rays of warmth. Some idea may be formed of the quantity of fuel thus wasted in smoke, by reflecting on the mass of foot that a few weeks' firing will lodge against the sides of the chimney; and yet this is formed only of those particles of the column of smoke which happen to touch the sides in its ascent. How much more must have passed off in the air? And we know that this foot is still fuel, for it will burn and flame as such; and, when hard caked together, is indeed very like and almost as solid as the coal from which it proceeds. The destruction of fuel goes on nearly in the same quantity in smoke as in flame, but there is no comparison in the difference of heat given. When fresh coals are first put on a fire, a considerable body of smoke arises. This smoke is, for a long time, too cold to take flame; but if a burning candle is plunged into it, the candle, instead of inflaming the smoke, will instantly be itself extinguished. Smoke must have a certain degree of heat to be inflammable. As soon as it has acquired that degree, the approach of a candle will inflame the whole body, and the difference of the heat which it gives will be very sensible. A still easier experiment may be made with a candle itself. Hold your hand near the side of its flame, and observe the heat it gives: then blow it out, the hand remaining in the same place, and observe what heat may be given by the smoke that rises from the still burning snuff; you will find it very little: and yet that smoke has in it the substance of so much flame, and will instantly produce it, if you hold another candle above it so as to kindle it. Now the smoke from the fresh coals, laid on this stove, instead of ascending and leaving the fire, while too cold to burn, being obliged to descend through the burning coals, receives among them that degree of heat which converts it into flame; and the heat of that flame is communicated to the air of the room, as above explained.

The flame from the fresh coals laid on in this stove, descending through the coals already ignited, preserves them long from consuming, and continues them in the state of red coals, as long as the flame continues that surrounds them, by which means the fires made in this stove are of much longer duration than in any other, and fewer coals are therefore necessary for the day. This is a very material advantage indeed. That flame should be a kind of pickle to preserve burning coals from consuming, may seem a paradox to many, and very unlikely to be true, as the doctor tells us it appeared to himself the first time he observed the fact: he therefore relates the circumstances, and mentions an easy experiment, by which his reader may be in possession of every thing necessary to the understanding of it. In the first trial he made of this kind of stove, which

was constructed of thin iron plate, he had, instead of the vase, a kind of inverted pyramid, like a mill-hopper; and fearing at first that the small grate contained in it might be clogged by cinders, and the passage of the flame sometimes obstructed, he ordered a little door near the grate, by means of which he could occasionally clear it; though after the stove was made, and before he had tried it, he began to think this precaution superfluous, from an imagination that the flame, being contracted in the narrow part where the grate was placed, would be more powerful in consuming what it should there meet with, and that any cinders between or near the bars would be presently destroyed and the passage opened. After the stove was fixed and in action, he had a pleasure now and then in opening that door a little, to see through the crevice how the flame descended among the red coals, and observing once a single coal lodged on the bars in the middle of the focus, he observed by a watch in what time it would be consumed: he looked at it long without perceiving it to be at all diminished, which surprised him greatly. At length it occurred to him, that he had seen the same thing a thousand times, in the conversion of the red coal formed in the snuff of a burning candle, which, while enveloped in flame, and thereby prevented from the contact of the passing air, is long continued, and augments instead of diminishing, so that we are often obliged to remove it by the snuffers, or bend it out of the flame into the air, where it presently consumes to ashes. He then supposed, that to consume a body of fire, passing air was necessary to receive and carry off the separated particles of the body: and that the air passing in the flame of the stove, and in the flame of a candle, being already saturated with such particles, could not receive more, and therefore left the coal undiminished as long as the outward air was prevented from coming to it by the surrounding flame, which kept in a situation somewhat like that of charcoal in a well luted crucible, which, though long kept in a strong fire, comes out unconsumed.

This stove of Dr. Franklin is very ingenious, and has been much used in France, where the management of coal-fires is but little understood, and they are therefore induced to use stoves in preference to open fires, when they burn pit-coals. Dr. Franklin completed the stove just described in 1771, and used it in London during three winters. While he was in France, he contrived another grate for burning pit-coals, which has the same property of burning the smoke, and at the same time the fire is exposed in a grate. The grate is a short cylinder, with its axis placed horizontally, and the end turned towards the apartment; one of its circular ends being made with bars, and the other is a back-plate: it is one foot (French) in diameter, and eight inches deep or long between the bars and the back: the sides and back are of plate-iron, the sides having holes of half an inch diameter, and three or four inches distant from each other, to let in air for enlivening the fire: the back is without holes, and the sides do not meet at either the top or bottom by eight inches: and this square space is filled with grates of small bars, crossing from front to back to let in air below, and let out the smoke or flame above. The three middle bars of the front grate, that is, the circular end, are fixed; the upper and lower may be taken out and put in at pleasure, when hot, with a pair of pincers. The whole of this cylindrical grate turns upon pivots fixed in the opposite sides, across the centre of it: the pivots are supported by a crotchet, the stem of which is an inverted conical tube five inches deep, which fits as many inches upon a pin, which is fixed upright in a cast-iron plate that lies upon the hearth. In the middle of the top and bottom grates

are fixed small upright pieces, about an inch high, which, as the whole is turned on its pivots, stop it when the grate is perpendicular. By this means the grate can be inverted by turning it over upon its pivots, but as that will prevent the back-plate to the apartment, it requires to be turned half round horizontally upon the conical pin to bring the front bars to the room.

In making the first fire in the morning with this grate, there is nothing particular to be observed: it is made as in other grates, the coals being put into the cylindrical grate above, after taking out the upper bar, which must be replaced when they are in.

The round figure of the front bars filled with fire, when thoroughly kindled, is agreeable: it represents the great giver of warmth to our system. As it burns down, it leaves a vacancy above, which must be filled with fresh coals, the upper bar is to be taken out, and fresh coals thrown in, the bar being afterwards replaced. The fresh coals, while the grate continues in the same position, will throw up, as usual, a body of thick smoke; but every one accustomed to coal-fires in common grates must have observed, that pieces of fresh coal stuck in below among the red coals, have their smoke so heated, as that it becomes flame as fast as it is produced, which flame rises among the coals, and enlivens the appearance of the fire. Here, then, is the use of this swivel-grate: by a push with the tongs or poker, it can be turned over on its pivots till it is inverted, and the front bars face the back of the chimney; then turn it gently round on its vertical socket or axis, till it again faces the room, whereby all the fresh coals will be found under the live ones, and the greater part of the smoke arising from the fresh coals will, in its passage through the live ones, be heated so as to be converted into flame. By this means much more heat is obtained from them, and the red coals are longer preserved from consuming. This construction, though not so complete a consumer of all the smoke as the vase, is yet fitter for common use, and very advantageous; it gives also a full sight of the fire always, a pleasing object which we have not in the other. It may with a touch be turned more or less from any one of the company that desires to have less of its heat, or presented full to one just come out of the cold; and when the front bars of the grate are supported in a horizontal position, a tea-kettle may be boiled on them.

Notwithstanding the acknowledged advantages of Dr. Franklin's construction of a stove, the expence and trouble of it, and the difficulty of procuring workmen who understood the manner of executing it, have prevented the general use of his stoves. Mr. James Sharp, with a view of obviating these objections and difficulties, has proposed several improvements, for which he has obtained his majesty's patent. According to the method which he proposes, they are easily accommodated to any rooms, where communication can be had with the external air; both to those which have, and those which have not chimnies: so that not only small rooms, but the largest halls, libraries, or churches, may be warmed in a more effectual manner than had ever been done before, and the greatest degree of heat produced from a given quantity of fuel. Mr. Sharp, by adding funnels to the top, renders these stoves fit for any chimney, and by lengthening the funnel, to any place without a chimney. By the hollow base with which his stove-grates are furnished, he is able to apply them with much greater effect to the external air, without any addition of brick-work; and by the alterations in the air-box, a much greater quantity of warm air is introduced than it was possible to introduce in their former state. If a stove of this kind is

to be placed in a common fire-place, a hole must be made through the back of the chimney, or through the hearth, to communicate with the external air; and this hole should be made as large as possible, and in a descending position, so that the outward air may ascend towards the stove. The hollow base of the stove must be placed against this hole, so as to cover it completely; and the bottom of the base must be fitted so close to the earth, and pointed with lime or putty, that the air may not pass. Upon the stove there must be put a few feet of iron funnel to reach above the breast of the chimney; and the chimney inclosed by iron plates, so constructed and placed in a square or oblong iron frame, that they may be easily removed when the chimney wants sweeping. By this construction, the warm air, introduced by the stove, will be carried into the room, which would otherwise pass up the chimney, and be lost. But if the stove is to be fixed in a room where there is no chimney, it may be placed in any part of it, where communication may be had with the outward air; and nothing more is necessary than a sufficient length of funnel to carry it through the roof, or wall, or window, or into any other chimney that may be convenient. If the fire-place be too small for the stove, the chimney may be closed by the aforementioned frame and plates, and the stove stand before the fire-place, and the smoke be carried off, by the help of a circular elbow, into the chimney above the mantle-piece. Many of these stoves, it is said, have been lately put up, in order to cure smoky chimnies, and have always succeeded. For farther particulars, see Sharp's Account of the Air-Stove Grates, &c.

The inhabitants of the northern parts of Europe have long been accustomed to the use of stoves in which the fire is shut up, and gives out its heat to a draught or current of air, which is made to pass through proper openings in the stove, and when sufficiently warmed, enters into the apartment. The smoke arising from the fuel is made to pass through a circuitous passage of flues, by which means the greatest part of the heat is absorbed. Stoves on this principle are known in England, but are very seldom used, except for warming of halls, staircases, and passages, in grand houses, as the English are not contented to feel the air warm, unless they see the fire. In Russia, Sweden, and other northern countries, they are indispensably necessary, as without them, it would be impossible to keep the rooms tolerably warm. A common fire-place has too large an opening, and if care be not taken to supply it continually with wood, &c. the heat it produces is hardly sensible, because it follows the current of the air, and is carried off by the smoke. These stoves, on the contrary, retain the heat a much longer time; and as their external parts, and also their flues, are very thin, they communicate their heat very readily, so that with a small quantity of wood, they warm an apartment much more than the fire of a common fire-place would do, with six times the quantity. For it was not sufficient that the inhabitants of these severe climates should discover the most simple means of keeping up in their houses a comfortable degree of heat, it was also necessary that this should be done with the least possible expence of fuel.

The stoves which they employ perfectly fulfil the above-mentioned intentions; they are also susceptible of every kind of ornament. The more surface we give to a stove constructed in this manner, the more the heat is increased, consequently we must not be surprised to find that this kind of stove sometimes occupies the whole height of an apartment, its width and depth being proportioned to its height.

The construction of these stoves is simple: they consist of

four, five, or more small chambers, built one above another : the lower one is for the fire which burns in it, and the smoke rising from it enters into the chamber immediately above, then into the third, and from that to the fourth. The passages or holes through which the smoke enters into one chamber from that beneath, are, in all cases, made at the corner of the chamber, opposite to the passage at which the smoke will pass out from the same chamber to the next above it. By this means the smoke is obliged to pass through the whole of the chamber, and has the greatest chance of transmitting its heat. A fire lighted in one of these stoves early in the morning, and with a small quantity of fuel, retains a strong heat during the whole day. The door of the fire-place is only opened to put in wood, and remains afterwards constantly shut. The wood lies upon a grate, consequently it is not buried in and stifled by the ashes. The ash-hole is spacious, and one or two feet in height, according to the capacity of the stove. Two doors are placed at the extremities of the ash-hole, and the current of air is very considerable, by which the smoke is carried up with great force, and the wood burns very briskly.

Stoves of this kind may be advantageously placed in halls, at the bottom of staircases, and in the anti-chambers of great houses : they may also, by proportioning their size to that of the rooms for which they are intended, be made use of in the houses of private persons. To this it may perhaps be objected, that the heat produced from these stoves is unwholesome, because they deprive the air of its moisture ; and that the air, by being made too dry, loses its elasticity, in consequence of which, respiration becomes difficult and laborious. These objections would appear of great weight, if we had not the example of the Russians, the Swedes, the Danes, the Germans, and in short of all the inhabitants of the north of Europe, to shew that those who are habituated to such stoves, do not find them unwholesome. If others should be sensible of inconveniences from the dryness of the air in the apartment, it may be easily removed by the very simple expedient of placing upon the stove a vessel of glass or earthen-ware, which has a large surface, and is very shallow : this being filled with water, will insensibly evaporate, and restore to the air that moisture of which the heat of the stove has deprived it : the air will then recover its elasticity. If orange-trees are exposed to the heat of such a stove, and the fire is not properly regulated, the plants grow yellow and lose their leaves, especially if the air is not changed, which in winter is not very conveniently done ; but if a vessel of water be placed upon the stove, the evaporation of the water will preserve the trees.

In a memoir published by M. Guyton in the *Annales de Chimie*, he has explained the construction of the stoves employed in Sweden, and recommends the adoption of one constructed on the same principle for general use in France.

The memoir is translated in the *Repertory of Arts*, 3d Series, vol. xvi. The construction of the stove which is there recommended may be improved, to adapt it to our use in England, where pit-coal is used : but the following principles, which the author lays down, are very useful as guides in making all kinds of stoves for warming apartments.

1. Heat is produced only in proportion to the volume of air consumed by the fuel.

2. The quantity of heat produced is greatest, (the quantity and quality of the fuel being the same,) when the combustion is complete.

3. The combustion is the more complete, in proportion

as the fuliginous part is longer retained in channels where it may undergo a second combustion.

4. The only useful heat is that sent out into, and retained in the space intended to be heated. The temperature of that space will be higher in proportion, as the current which must be renewed from without to support the combustion, is less enabled to take up in its passage the heat produced.

Hence the following inferences evidently arise :

1. The fire-place ought to be insulated from all bodies that are rapid conductors of heat. All the heat that goes out of the apartment is absolutely lost, unless intentionally directed into another apartment.

2. Heat being produced only by combustion, and combustion being sustained only by a current of air, the current should be brought in by channels, where the needful rapidity may be preserved without being too distant from the space to be warmed, so that the heat it there deposits, may be gradually accumulated in the whole of the insulated furnace, in order afterwards to flow out of it slowly, according to the laws of the equilibrium of that fluid.

3. The wood being so far consumed as to give no more smoke, it is advantageous to close the mouth of these channels, in order to retain there the heat that would otherwise be carried off through the upper flue, by the continuance of a current of fresh air, necessarily of a low temperature.

4. Lastly ; it follows from these maxims, that all things being equal, a higher temperature will be obtained, and supported during a much longer time, by forming, in the internal parts of the stove, or under the hearth of a chimney, and in their vicinity, tubes in which the air that comes from without may be warmed before it enters the apartment, to serve the purpose of combustion, or replace that which has been consumed. These have been called *bouches de chaleur* (mouths or apertures of heat) ; because, instead of contemplating their principal use and intention, it is commonly imagined that they are only made in order to give by their issues a more rapid current to the heat produced. Nor is this idea absolutely devoid of foundation, since the air that issues from them has only changed its temperature, by carrying off a portion of the heat that would have remained in the interior. Those, however, who would prescribe them, as opposing the most important object, which is the retaining of the heat as long as possible, do not consider that they may be closed, and all communication with the external air cut off by a simple slide, and, therefore, it is easy to derive from them every possible advantage without any inconvenience. And we may add, that in small apartments, or such as are accurately closed, they are often indispensibly requisite, if we could avoid being exposed to currents of cold air. Dr. Franklin very justly quotes a Chinese proverb to this effect : " Shun a current of air from a narrow passage as you would the point of an arrow."

The Swedish or Russian stoves, which have chambers for the reception of the flame and smoke, are little known in this country : but those which are in common use in the halls and vestibules of our great houses are French stoves. They differ from the others in having a very great length of small flues or winding passages, through which the smoke passes, and communicates its heat to the air, which circulates in similar passages, until it becomes warmed, and makes its exit through the mouths into the apartment. This method is not so simple as the small chambers or apartments of the Russian stoves, nor is it so good in the long run ; because the passages are very liable to become clogged with soot ;

and even before they are so clogged as to intercept the passage of the smoke, the transmission of the heat is much impaired, because the interior surfaces of the flues becoming coated with soot, do not conduct the heat so rapidly, and in consequence, a great part will still pass out into the chimney. Also, these flues with small passages require a stronger draught in the chimney, to make the air pass through the passages, than when chambers are used.

The Holland iron stove, which has a flue proceeding from the top, the fire-place and ash-pit being closed by small iron doors opening into the room, comes next to be considered. It is frequently made of iron-plate, and is most commonly called a German stove. Its conveniencies are, that it makes a room warm all over, for the chimney being wholly closed, except the flue of the stove, very little air is required to supply that, and therefore not much rushes in at crevices, or at the door when it is opened. Little fuel serves, the heat being nearly all saved; for it radiates almost equally from the four sides, and the bottom and top, into the room, and presently warms the air around it, which being rarefied rises to the ceiling, and its place is supplied by the lower air of the room, which flows gradually towards the stove, and is there warmed and rises in its turn, so that there is a continual circulation, till all the air in the room is warmed. The air, too, is gradually changed by the stove-doors being in the room, through which part of it is continually passing, and that makes these stoves more wholesome, or at least more pleasant, than the German stoves, next to be spoken of. But they have the inconvenience that there is no sight of the fire, which is in itself a pleasant thing, nor can any other use be conveniently made of the fire but that of warming the room.

When the room is warm, people not seeing the fire are apt to forget supplying it with fuel till it is almost out, then growing cold, a great deal of wood is put in, which soon makes it too hot. The changes of air are not carried on quick enough, so that if any smoke or ill smell happen in the room, it remains a long time before it is discharged. For these reasons, the Holland stoves have not been much introduced among the English (who love the sight of the fire), unless in some workshops, where people are obliged to sit near the windows for light, and in such places they have been found of great use.

The real German stove is made like a box, one side wanting, and that side is built against the wall of the room. It is composed of five iron-plates screwed together, and fixed so as that the fuel can be put into it from another room, or from the outside of the house. It is a kind of oven reversed, its mouth being without and body within the room that is to be warmed by it. This invention certainly warms a room very speedily and thoroughly with little fuel: no quantity of cold air comes in at any crevice, because there is no discharge of air which it might supply, there being no passage into the stove from the room. These are its conveniencies. Its inconveniencies are, that people have not so much sight or use of the fire as in the Holland stoves, and are moreover obliged to breathe the same unchanged air continually, mixed with the breath and respiration from one another's bodies, which is very disagreeable to those who have not been accustomed to it.

This may be remedied by making a small aperture into the flue, with a register to draw off the air. This kind of stove is still less in use in England than that which we have before described, and which is generally called the German stove, although it is used by the Dutch instead of the Germans.

Messrs. Strutt, in their extensive cotton-mills at Belper,

in Derbyshire, have employed a kind of stove which is found to answer extremely well; it consists of what is called a cockle, that is, a square chest or vessel of iron-plate, rivetted together in the manner of a boiler, and set in a furnace, so that a fire can be made withinside of it upon a grate, and the smoke will pass off through a small passage into the flue which conducts to the chimney, the passage of which is regulated by a sliding damper. The cockle is of considerable dimensions, as much as four feet square and five feet in height, and the fire is made at the bottom of it, upon a grate of about fourteen inches by eighteen, so that the fire does not anywhere touch the inside of the cockle, but the heat rising up therein gives a considerable and equable heat, without rendering it so hot as to burn the air which it is intended to warm, for if that is once done the air will be rendered unpleasant.

The cockle is inclosed in a casing of brick-work, which is of the same shape as the cockle, and leaves a space all round between of a few inches. This case of brick-work is again surrounded by walls of brick-work, leaving a space of about eighteen inches all round; and these walls are carried up above, to form the chimney or funnel to convey the warmed air up to the several apartments of the mill. This chimney is divided, by thin brick partitions, into as many different flues as there are floors to be warmed; and a small opening is made, with a register, from each flue into the apartment it is intended to supply. This opening is made close to the floor; and in order to make a change of the air, ventilators are placed high up in the apartment, so as to be near the ceiling.

This division of the chimney into several different flues is intended to equalize the supply of air to the several apartments, and by this means the upper apartments are equally well supplied with warm air as those below.

In order to make the air pass in contact with the surface of the heated cockle, a horizontal partition is built in the space between the chimney and the brick-casing of the cockle. The level of this partition is at about one half the height of the cockle, and its effect is to divide the brick-casing of the cockle into two halves, one above the partition and the other below. The cold air is freely admitted into the lower part of the chimney beneath the partition, but cannot escape into the chimney above it, without entering into the space between the cockle and its brick-casing, through a number of small openings made in it beneath the horizontal position; and in thus passing in contact with the surface of the cockle the air becomes heated, and passes out again, through openings in the brick-casing, into the chimney above the partition. In order to make the cold air strike more forcibly against the heated surface of the cockle, a small iron tube is fitted through each of the openings in the lower part of the casing, and the ends of these tubes approach very near to the surface of the cockle. Mr. Strutt has introduced this kind of stove into the new Infirmary at Derby, and in several other similar institutions it has been adopted with great success.

In 1799, Mr. James Burns of Glasgow took out a patent for an improved stove, or fire-grate, to burn with an open fire: his stove has a very elegant appearance, and several advantages. The object of the improvement was to prevent the heat generated by combustion, and thrown out into the apartment by radiation, from being unnecessarily wasted by the draught of air for the support of the fire, as is usual in stoves or grates of the common construction; where all the air that goes to maintain the combustion is furnished from the warm air in the room, the waste of which is supplied by the exterior cold air, which comes pouring into the room at the

bottoms of the doors, or by the sides of the windows, and thereby undoes a great part of the effect that otherwise would be produced by the fire. To accomplish this intention, the air that maintains the fire in the improved stoves is brought through a tube, which is called the air-tube, from the outside of the house, and may be made to pass between two of the joists, (where the floors and ceilings are close enough to allow this,) so as to be brought to the bottom bars of the grate, without having any communication with the interior air of the room; while, at the same time, the grate and parts connected with it are so constructed, that when the fire is not wished to be supplied with cold air from the outside of the house, the passage may be shut more or less perfectly by means of a valve, a small door, a cock, or any similar contrivance. When convenience does not admit of the air-tube being carried to the outside of the house, it may be carried to a cellar, larder, or stair-case, and the same end will be gained, with this farther advantage, that such cellar, or other apartment, will be always well ventilated, and prevented from acquiring or retaining any unhealthy or disagreeable smells.

The principle is to supply the fire with air from without the room or apartment, so as to prevent the warm air of the room from being drawn to the fire-place and hurried up the chimney, while, at the same time, all the advantages of open grates may be enjoyed.

The form of Mr. Burns' stove is that of a vase or urn placed in the chimney-place, which is made circular, to form a niche for its reception. The urn is open at top, and the sides are formed of open work or grating, with a grated bottom, forming a sufficient space to contain the fire; but the pedestal and lower part of the vase are made close, to prevent the entrance of air to the fire, except that which passes up from the air-tube through the hollow pedestal; and within this pedestal is an air-valve, which opens and shuts by a register, to regulate the entrance of the current from the open air. In the pedestal of the vase is a drawer, to receive the ashes. The niche or chimney in which the vase is placed, has the usual opening at top to carry off the smoke. The air for the support of the fire enters from the external air, through the tube or air-pipe before described, and passes into the hollow pedestal of the vase; and having passed through the hollow neck or stem of the vase, it finds no difficulty in passing up through the bottom of the grate, the back or side of the ash-drawer next which the aperture is being made low, to allow it to flow in freely. The grate and its internal cavity may be of any convenient form, but circular or elliptical will answer best, especially when another improvement is applied. This is a glass plate or iron-work fence or screen, to prevent those dreadful accidents which so frequently occur of ladies' or children's clothes being set on fire by sparks from the grate. Where this safe-guard fence or screen is wished to be applied, the inside of the chimney where the grate is to stand must be a semi-cylinder, or nearly so, with a lining or cover, made of metal, at such a distance from the semi-cylindrical wall or niche in which the stove is placed, as to give sufficient room for allowing the safe-guard or fence to be slid round into it, when the fire is wished to be left open to introduce fresh fuel, or when the drawer with the ashes is to be removed. The fence is a frame-work of metal, which, when filled up with glass, or with wire-work, forms a portion of a cylinder, answerable to the curvature of the space between the back of the chimney and the lining above-mentioned, made in one or two pieces, and moving in a circular groove in the hearth, which serves to conduct it into its place behind the grate, when the fire-place is

wanted to be left open, as before-mentioned. The top of the front of the opening (the chimney-piece) projects in a circular form, or is furnished with an added projection, made of metal, and furnished with a circular groove on its under surface, of the same radius as the groove in the hearth, for the purpose of guiding the upper part of the frame of the guard. The glass with which the frame of the guard is filled may be stained or painted: complete safety is thus obtained, and, at the same time, the comfort arising from the view of a cheerful fire is not prevented by the interposition of any opaque body. But for nurseries or the like, where convenience and safety are more the objects than elegance or luxury, the frame-work may be filled up with wire-work.

Instead of such grooves at top and bottom for the fence to move in, the fence itself may be furnished with a groove at its top and one at its bottom, to receive any projecting piece of metal, or other substance of a proper curvature; or its bottom groove may receive the upper edge of the fender, which, being made to a proper curve, and properly adjusted and kept in its place, will answer the same end. But whichever of these ways be followed, or whatever other method of construction (for it may easily be varied to answer circumstances), rollers or castors should be provided at the lower part of the fence, to make it move with greater ease, either to the front of the grate, or into the space between the back of the chimney and the lining above-mentioned. Where either the glass or the wire-work frame, or both of them, are meant to be applied to square or rectangular chimnies, without the trouble of giving them a semi-cylindrical form, the lining to receive the fence or fences may be introduced at the sides, or jambs, of such chimnies; or the fence may be made to rise, by means of pulleys, into the wall above the opening, or be slid sideways into the walls at the sides of the openings.

Besides the advantages already pointed out as connected with them, these stoves possess also the following; any room or apartment may be heated by their means with a much smaller quantity of fuel than by common open fires; at the same time, the advantage of seeing the fire is not lost, as in close stoves, for these grates have side as well as bottom bars, which allow the radiant heat and light to be thrown out into the room, without any impediment; and, in fact, large rooms, halls, and the like, which by the usual methods can hardly be warmed, or made at all comfortable in cold weather, may, by means of these improvements, be heated as effectually as the smallest apartment; for when their full effect is wanted to be procured, it is only necessary to keep the fence in its recess, that even that portion of heat which would be kept back by the interposed glass or wire-work, may be thrown out into the room, and perform its office.

In 1804, Mr. Joshua Jowett of London obtained a patent for a very similar contrivance, which he called a fire-guard stove, which is intended to prevent accidents from sparks of fire flying out. The stove itself is an open fire, and is usually made of a cylindrical form, the axis of the cylinder being vertical. One half of the cylinder which faces the apartment is made with bars at the lower part, to contain the fire, and an opening over them to feed it. The back part of the cylinder is made of cast-iron plate; but, instead of the brick-work being built up close round the back, a small space is left to receive the guard. The weight of the stove or grate is supported upon a vertical iron bar, which is in the centre, or axis of the cylinder, which forms the stove, and the guard swings round upon this bar as a centre, and being a half-cylinder of wire-work, can be brought in front to inclose

the fire, or it can be turned round behind the stove out of sight.

The fire-guard may be fixed to any stove which will admit of two centres or pivots being placed in a perpendicular line in the back of the stove, to suspend the fire-guard, and guide its motion; and the stove must admit of grooves on either side, for the guard to pass through, as the levers will direct. The principle of the action of the fire-guard, is that of being united to two centres or pivots, placed perpendicular one to the other; and it is connected to the two centres fixed to the stove by means of two lever-cranks, one end of which is fixed to the guard, and the other end of each to the centres or pivots, by which the guard swings in a rotatory motion, passing through a groove formed in the stove on either side, to swing before the fire when required, and is brought into use by means of a handle or knob, fastened to the front edge of the frame of the guard for that purpose; or, instead of drawing it out with the hand, as before described, it may be brought into use by means of a spring fastened to the crank, and pressing against the cheek or back of the stove, to throw the guard forward. The same effect may be produced by means of a balance fastened to any part of the fire-guard, and working with a line or chain over pulleys fixed to the stove, or by means of the combined force of the spring and balance.

Mr. Allan Pollock took out a patent, in 1807, for a stove which is very similar to the Swedish stoves, having chambers through which the smoke is successively conveyed, and gives out its heat to the air of the apartment in which it is placed: in addition to this, the stove is made to give a constant current of warmed air; for this purpose, the cold air is made to enter and circulate through winding passages, situated in the back of the fire-grate, or space in which the fire burns, and the same passage is continued, by an iron tube, through the smoke-chambers up to an air-chamber situated in the top, from which it passes into the apartment. These stoves are made of cast-iron; but, to prevent the air receiving any taint from passing in contact with the hot iron, Mr. Pollock proposed to apply a composition to the cores of the moulds in which the pipes are to be cast, which composition will become vitrified by the heat of the melted iron, when the same is poured into the mould, and will form a glassy or vitrified lining to the tubes, and prevent the actual contact of the air with the iron. These stoves answer very well.

A very important improvement in those fire-places for burning of coal, which are generally called register-stoves, has been lately made by Mr. John Cutler of London, for which he had a patent in 1815. The stoves constructed by him are nearly such as are known by the name of register-stoves, being made of cast-iron plate to inclose the fire-place at the back and sides, but open in front to the apartment; leaving only a passage for the smoke through a register, at the upper part of the inclosed space. Mr. Cutler's improvement consists in applying to such grates or stoves a chamber, or magazine, situated beneath the grate (or the space inclosed by grating) in which the fire is to burn. This chamber is to contain a magazine of fuel sufficient to supply the combustion for a whole day, or other required space of time: the bottom plate of the chamber is moveable; and by means of a wheel and axle, the fuel contained in the magazine can be elevated, so as to introduce a portion of the fuel into the grate at the lower part, or from beneath; and thus, from time to time, replace the fuel which is consumed, without the trouble of occasionally throwing on coals.

In order to make the fire burn, the flue or entrance to

the chimney must be of such a construction, as will produce the most efficient draught or current of air to pass through and across the top of the fire. This improvement of introducing a supply of fuel into the grate from beneath, causes the fire to burn clear and with little smoke; because the smoke, or gas, which issues from the newly introduced fuel, when it is first heated, must of necessity ascend through the burning fuel, and be thereby consumed. Another improvement is to reduce the fire, or extinguish it, when it is left for the night. This is done by lowering down the whole of the fire from the grate into the chamber, or magazine, beneath the grate: the supply of air is thus interrupted, and the fire is completely inclosed in a deep chest, so that it is impossible sparks can fly out, and the fire soon becomes extinguished. The advantages of these improvements are by no means trifling. By burning the smoke, the whole effect of the fuel consumed is produced; and were this invention universally introduced into London, that pernicious sooty atmosphere in which it is hidden would be so improved, as to be equally pure with that of Paris, or other continental cities, where wood alone is used for fuel. The burning of the smoke renders the sweeping of the chimnies unnecessary, and the danger of fire from the soot contained in the flue is avoided: also chimnies which throw out smoke into the room will, in almost all cases, be cured by this improvement, because the quantity of air or gas which must pass through the chimney is so small. To avoid the trouble of throwing on coals, and to have at all times a bright and cheerful fire, are matters of convenience, but are not wholly to be overlooked: and, lastly, to have the means of extinguishing the fire, when it is left for the night, is a most important improvement; when it is considered that, amongst the fires which happen every year in London, how many break out in the hours when the fires are left, and a great proportion are doubtless occasioned by fires left unextinguished.

The machinery for raising up the moveable bottom of Mr. Cutler's stove is very simple. The magazine-chamber is composed of iron plates screwed together, and the moveable bottom is fitted to it, so as to leave as small a space round the edges as possible. A bar is fixed across, beneath the bottom plate; and the ends of this bar pass through slits, or narrow openings, in the side plates of the chamber. To the extremities of the bar the ends of two chains are attached, and the upper ends of these chains are made to wind upon the ends of a horizontal axle, which extends over the top of the stove, so as to be within the chimney, and out of sight. The axle is turned round by a face or crown-wheel, fixed upon the extremity of it, and the teeth thereof are engaged by the teeth of a small pinion, the axis of which comes through the iron work of the stove; and the end has a small square hole in it, to receive a square or key upon a small winch handle. By means of this handle, the iron axle is turned round, and winds up the chains, so as to elevate the bottom plate of the magazine, and thereby raise up a portion of fresh fuel into the lower part of the grate, where it is burned, as before mentioned; and the smoke which first issues from the coal rises through the fire, and is thereby consumed.

Mr. Cutler has made a great number of these stoves, which are found to answer very well: they have all the same properties as Dr. Franklin's cylindrical grate, but in a greater degree; and the fire can be supplied with fresh coals at the lower part, without the trouble of inverting the grate.

STOVES, *American*, are contrivances for warming of

STOVE

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rooms, &c. by a continual introduction and exchange of dry fresh air. These stoves are called American, because the first patterns in cast-iron upon this principle were the

invention of Dr. Franklin, who then resided in Philadelphia.
See FIRE-Places.

Steam-tin

STREAM-Tin, in *Minerology*. Particles or masses of tin-ore found beneath the surface of alluvial ground in low situations, or in vallies, are called *stream-tin* in Cornwall and Devonshire, from the process used to separate the earthy matter from it, which consists in passing a stream of water over it. The particles of stream-tin are generally rounded by attrition. The ore is of the best quality, and is sometimes intermixed with particles of native gold. See the following articles, and **TIN**.

STREAM-Works. The alluvial repositories of tin-ore are called stream-works. (See the preceding article.) They consist of beds or strata of particles, and rounded pieces of tin-stone, covered by alluvial deposits of sand or gravel. The formation of these repositories in Cornwall is owing to the soft decomposing state of the rocks, which are intersected by metallic veins. Tin-stone or tin-ore possesses great hardness and specific gravity, and when carried down by rivers or floods, is separated from its matrix by the action and re-action of the water, and spread into layers, which are afterwards covered by beds of sand, clay, or gravel, over which another layer of stream-tin is sometimes found covered with an upper deposit of alluvial matter. That stream-tin has been carried down to the situations in which it now occurs, is proved from another circumstance,—fragments and masses of rock are found with it, which, in many instances, serve to identify the rock from whence it came, being different from the rocks in the vicinity, and often possessing some characteristic appearance by which it can be immediately known to the miners of the country. Almost all the rocks of Cornwall are in a state of rapid disintegration, and have evidently been much higher than at present at some former period. Many of the stream-works or repositories are of very ancient date, as they occur considerably below the present level of the rivers. Human skulls, and the horns of the elk, or stag, have been found in the beds of sand which cover them. In the stream-works near St. Austle, pieces of native gold, from the size of a bean to that of an hazel-nut, were occasionally found; and a piece of a vein of quartz from the same place, about one-third of an inch thick, containing imbedded globules of native gold, the size of large shot, is in the possession of Mr. Hennah, of Plymouth: the latter is important, as proving that gold once existed in regular veins. In St. Blazey Moor there is a depth of twenty feet of alluvial soil. The first stratum next the sur-

face is composed of gravel resting upon mud; the succeeding stratum is gravel, containing a little tin-ore: this lies upon a bed of dark combustible peat-earth. Immediately under this lies a bed of stream-tin, about five feet thick. Great part of this stream-tin had been wrought out at a very remote period, and before iron instruments were in use; for several wooden pick-axes, made of oak, holm, and box, were discovered in it a few years since. Stream-works sometimes extend under the sea on the coast of Cornwall. One of the most remarkable of these works is in a branch of Falmouth harbour. That variety of tin-ore called wood-tin is found in stream-works, but is not at present met with in regular tin-veins.

In some parts of the mining districts of Derbyshire, lead-ore is met with in alluvial depositions. Mr. Farey, in his Derbyshire Report, p. 373, mentions a mass of lead-ore, 25lbs. weight, being taken out of a gravel at the top of a hill in the village of Wyanton, which proves that masses of lead-ore have in former times been carried far from their native situations; and the reason why they are not more frequently found, arises from their being softer and more perishable than tin-ore. Many of the alluvial repositories of gold have a similar origin to the stream-works of Cornwall. The gold, being heavy and imperishable, has remained, while the materials in which it was imbedded have been washed away. See **VEIN**.

STREAMING, or **STREAM-Works**, denotes the management of the stream-tin. The first part of this business, after securing the ground which contains it, is to sink a hatch, or shaft, three, five, or seven fathoms deep, to the rocky shelf or clay on which the tin is stratified. If, upon trying a shovel of it, it be worth working, the operator digs an open trench in the lowest part of the valley, which he calls a *level*; and this serves to drain off all water from the workings. Those places that are rich in ore are called *beubryle*, or living-streams. The streamer next carries off what he calls the over-burden, *i. e.* the loose earth, rubble, or stone which covers the stream; and the stream-tin is dug up and washed at the same time, by casting every shovel of it as it rises into a *tye*, which is an inclined plane of boards for the water to run off, about four feet wide, four high, and nine feet long: in which, with shovels, they turn it over and over again, under a cascade of water which washes through it, and separates the waste from the tin, till it becomes one half

tin. The best of the tin is collected by its superior gravity, in the head of the tye, under the cascade; and the refuse and soil are cast into the beds of adjacent rivers, or buried under the gravel and stones that form the interior strata. This kind of tin is dressed by washing it again in a smaller tye, called a *gounce*, with a less current of water, and greater care. The richer part is put into large vats, and the waste is dressed again, till what remains becomes refuse; the tin is then sifted through wood or wire sieves, which separate the greater and smaller particles: the smallest tin is put into another firmly weaved horse-hair sieve, called a *diluter*, by which it is made saleable.

Some of the nodules of tin are smelted as they come out of the tye; but those which are mixed with water, as well as the refuse of the poor tin, which were in the tails of the tye and gounce, are triturated and pulverized in the stamping-mill, so that all waste may be cleared from the tin by several ablutions, as in the dressing of mine-tin. See *Dressing of ORES*.

Beside these stream-works, there is another sort, occasioned by the refuse from the stamping-mills, &c. which are carried by the rivers into the lower grounds, and after lying some years and collecting there, yield some money to the laborious dressers, called *lappiors*, probably from the Cornish word *lappior*, or dancer, from the method of

moving up and down with naked feet in the buddles, to separate the tin from the refuse. Stream-tin is then carried to the blast-furnace, called the blowing-house, in which a fire is made with charcoal, excited by two large bellows, which are worked by a water-wheel. The tin and charcoal are laid in a furnace, made by moor-stones and clay, well cemented and cramped together with iron, called the *castle*, *stratum super stratum*, in such quantities, that from 8 to 12 cwt. of tin, by the consumption of from 18 to 24 sixty-gallon packs of charcoal, may be smelted in a tide, or twelve hours' time. The tin is forced out by the blast of the bellows, through a hole at the bottom of the earth, into a moor-stone trough, called the *float*; whence it is laded into less troughs or moulds, each of which contains about 3 cwt. of metal, called slabs, blocks, or pieces of tin, in which size and form it is sold in every market in Europe. This, on account of its superior quality, is known by the name of *grain-tin*, which formerly fetched a price of 7*s.*, and of late is advanced to 10*s.* or 12*s.* more *per* cwt. than mine-tin is sold for, because it is smelted from a pure mineral by a charcoal fire; whereas mine-tin is usually corrupted with some portion of mundic, or other minerals, and is always smelted with a bituminous fire, which communicates a harsh sulphurous quality to the metal. Pryce's Mineral. p. 136, &c.

Strength

STRENGTH, *viz.* force, or power.

It has been said that the strengths of different animals of the same species, or of the same animal at different times, are in a triplicate proportion of the quantities of the mass of their blood: the whole strength of an animal being the force of all the muscles taken together; therefore, whatever increases strength, increases the force of all the muscles, and of those serving digestion, as well as others. See **MUSCLE**.

Yet, though the truth of this observation be allowed, the quantity of blood may be increased in such circumstances as to abate the strength. The equilibrium between the blood and vessels being destroyed, wonderfully lessens the strength. The sudden suppression of perspiration, though it increases the quantity of the blood, as it must considerably do so, by Sanctorius's calculation, yet it lessens the strength; because the retained matter, being what ought to be evacuated, so alters the texture of the blood, as to make it unfit for muscular motion.

Suppose the increase of quantity to be connected with an extraordinary viscosity, the quantity of small separable parts decreasing as the viscosity increases, the quantity of animal spirits separated in the brain will be less; and the tension of the fibres being in proportion to the animal spirits forced into them, they will not be able to counterpoise the great weight of the blood, and so the strength will be diminished.

Bellini proves, that if the blood be so vitiated as to increase or diminish strength, it amounts to the same as if the blood were in a natural state, but its quantity increased or diminished in the same proportion: so that the blood, when vitiated, may so impair the strength of the muscles, as even to spoil digestion; and yet, in some cases, it may be so vitiated as to help digestion, and increase strength.

M. de la Hire, in a calculation of the strength of a man in drawing and bearing, shews, that the strength of an ordinary man walking in an horizontal direction, and with his body inclining forwards, is only equal to twenty-seven pounds; which is much less than one would have imagined.

He adds, that this force would be much greater, if the man were to walk backwards; and that it is for this reason, that watermen fetch their oars from before backwards: and though, he observes, the gondoliers of Venice fetch them the contrary way, yet this is, because they choose to lose the advantage of strength, to have that of seeing the place they are going to, in the numerous turns and canals they there meet with.

It is known by experience, that a horse draws, horizontally, as much as seven men; consequently, his strength will be 189 pounds. A horse, as to pushing forwards, has a great advantage over a man, both in the strength of its muscles, and the disposition of the whole body; but the man has the advantage over the horse in ascending. M. de la Hire shews, that three men, laden with 100 pounds a-piece, will ascend a pretty steep hill with more ease and expedition than a horse laden with 300 pounds.

Hakewell, in his *Apology*, p. 238, furnishes us with abundance of instances of extraordinary strength.

STRENGTH of a Sentence, in *Grammar* and *Rhetoric*, denotes such a disposition or arrangement of the several words or members, as shall bring out the sense to the best advantage, render the impression which the period is designed to make most full and complete, and give every word and every member their due weight and force. A sentence, as Dr. Blair observes, may be sufficiently clear, and possess the requisite compactness or unity; and yet, by some un-

favourable circumstance in its structure, it may fail in that strength or liveliness of impression, which would have been produced by a more happy arrangement. The *first* rule, which this writer gives, for promoting the strength of a sentence, is to divest it of all redundant words and members. The *second* rule is to attend particularly to the use of copulatives, relatives, and all the particles employed for transition and connection. The *third* rule is to dispose of the capital word or words in that part of the sentence in which they will make the fullest impression. The *fourth* rule is to make the members of sentences go on rising and growing in their importance above one another; which kind of arrangement is called a *climax* (which see): in other words, a weaker assertion or proposition should never come after a stronger one; and when a sentence consists of two members, the longest should, generally, be the concluding one. The *fifth* rule is to avoid concluding sentences with an adverb, a preposition, or any inconsiderable word; because such conclusions are always enfeebling and degrading. Besides particles and pronouns, any phrase, which expresses a circumstance only, always brings up the rear of a sentence with a bad grace. Another rule, relating to the strength of a sentence, is this: that, in the members of a sentence, when two things are compared or contrasted to each other, where either a resemblance or an opposition is intended to be expressed, some resemblance in the language and construction should be preserved; for when the things themselves correspond to each other, we naturally expect to find the words corresponding too. We might here add, that the sound, harmony, and easy flow of the words and members of sentences, contribute to promote their strength and effect. This rule comprehends the choice of words, and their arrangement; the order and disposition of the members, the cadence or close of sentences, and the sound of words as adapted to their signification. For the illustration and application of these rules, we refer to Blair's *Lectures*, vol. i. and Murray's *Grammar*, vol. i. See **STYLE** and **NUMBERS**.

STRENGTH and Strefs of Materials, in *Mechanics*, is a subject of very considerable importance, and one which, of all the branches of this useful science, is the least understood. We have, indeed, two or three distinct theories by different authors, for estimating the strength of beams, and other materials, according as they are placed in this or that position; but it unfortunately happens that we owe all these theories to men who have not themselves made any experiments, and have, therefore, no better foundation than mere hypothesis, and consequently are not only discordant amongst each other, but totally at variance with practical results. The authors to whom we more particularly allude in this place, are Galileo, James Bernoulli, Leibnitz, Euler, and Lagrange; names certainly of the first eminence as philosophical mathematicians, and whose respective investigations, while we only contemplate the analytical processes of them, are highly honourable to the genius and talents of their authors: but when we consider them with reference to their practical application, we are obliged to admit that they are almost entirely useless. Had the materials the properties these authors suppose, *viz.* were they perfectly elastic in one case, or perfectly rigid and incompressible in another, then we should doubtless find the results such as have been deduced; but we know that, practically, none of these properties are found to have place. We know of no bodies either perfectly hard, or perfectly elastic; we know of no bodies that are either

wholly incompressible, or inextensible; and, consequently, of none to which these theories will apply: being each founded upon some hypothesis, which necessarily involves one or other of these principles as their bases.

There is, however, another class of men to whom we are indebted for many varied experiments; but not one of them, we believe, has ever attempted to establish any theory, as founded upon the facts which these experiments have established. Of the latter class are more particularly to be distinguished Mariotte, Parent, Belidor, Muschenbroeck, and Buffon, particularly the latter, who, with Du Hamel, was employed by the French government in making experiments on a very considerable scale; but unfortunately M. Buffon conducted them rather as a natural philosopher than as a mathematician, and, therefore, did not deduce from them those useful practical results, which might *a priori* have been expected. Our countryman, Emerson, also made some experiments on the strength of various materials; but little confidence is, we believe, to be placed on his determinations. They appear to have been made in too gross a manner to be at all depended upon, to form the groundwork of any calculations; as, in some cases, they nearly double the strength which has been found by other and more accurate experiments; while, in some, they make it not more than half. Thus, Emerson says, that a piece of oak, a yard long and an inch square, when supported at its two ends, bore, before breaking, 330 pounds; whereas Belidor makes the strength only 187 pounds; and we have repeated the experiments on several pieces of oak of the same dimension, and have found a very accurate agreement between them, and the mean given by the latter author, *viz.* 187 pounds. The direct strength of cohesion of the different woods given by Muschenbroeck and Emerson are also much at variance with each other; and though we ought not perhaps, in such a case, to give our entire confidence to either, yet the care Muschenbroeck appears to have taken, and the minuteness with which he describes the processes he employed, cannot but incline us to adopt his results, in preference to Emerson's, till some farther experiments have been made, that, from their number and accuracy, may inspire us with greater confidence. Such a course of experiments is now carrying on at the Royal Military Academy, Woolwich, by Mr. Barlow of that institution; and as nothing will doubtless there be wanting to render the course complete, either with regard to the selection of proper woods, or the accuracy of the workmanship that may be required, the publication of them will doubtless be very interesting, as the means of supplying a great desideratum amongst the scientific engineers of this country. "This subject," says Dr. Robison, "is of so much importance, that in a nation so eminent as this for invention and ingenuity in every species of manufactures, and in particular so distinguished for its improvements in machinery of every kind, it is somewhat singular that no writer has treated of it in the detail, which its importance and difficulty demand. The man of science, who visits our great manufactories, is delighted with the ingenuity which he observes in every part, the innumerable inventions which come even from the individual artificers, and the determined purpose of improvement and refinement which he sees in every work-shop. Every cotton-mill appears an academy of mechanical science; and mechanical invention is spreading from these fountains over the whole kingdom. But the philosopher is mortified to see this ardent spirit so cramped by ignorance of principles, and many of these original and brilliant thoughts obscured and clogged with needless and even hurtful additions, and a complication of

machinery which checks improvement, even by its appearance of ingenuity. There is nothing in which this want of scientific education, this ignorance of principle, is so frequently observed, as in the injudicious proportion of the parts of machines, and other mechanical structures; proportions and forms of parts, in which the strength and position are in no wise regulated by the strains to which they are exposed, and where repeated failures have been the only lessons."

Without entering here upon the subject of corpuscular attraction, and the law of cohesion which the particles of bodies observe, according to their different arrangements, a topic that would carry us far beyond the limits we can assign to this article, and on which, after all, so little satisfactory information is to be expected, we shall proceed to examine the different strains to which a body may be exposed, and its tendency to resist fracture, according to its magnitude, form, and position.

A piece of solid matter may be exposed to four different kinds of strain, *viz.*

1. It may be torn asunder by some force applied in the direction of its length; as in the case of ropes, stretchers, king-posts, tie-beams, &c.
2. It may also be crushed by a force applied in the direction of its length; as in the case of pillars, posts, and truss-beams.
3. It may be broken across by a force acting perpendicularly to its length; as in joists, levers, &c.
4. It may be wrenched or twisted by a force acting in a kind of circular direction at the extremity of a lever, or otherwise; as in the case of the axle of a wheel, the nail of a press, &c.

On the direct Cohesion of Bodies.—The first of these strains is by far the most simple, as to its physical operation; though it is that of all others, perhaps, that comes least under the consideration of a mechanic or engineer: and when it is the subject of contemplation, if any former experiment can be had recourse to, it is sufficient for his purpose; as no possible cause can be assigned, nor any reason offered, for supposing but that, in such cases, the strength varies directly as the area of the section of fracture, and is totally independent of the length or position; except, indeed, so far as the former may increase the weight or force, when the body is suspended in a vertical direction, or in any other position where the weight of the body itself increases the force applied. Abstracting from this, every part is equally liable to fracture, being throughout stretched by the same force. But this supposes a perfect uniformity of corpuscular action, or of the attraction of cohesion, which is probably not the case in any body in nature; and, therefore, as the longest body, may be supposed to offer the greatest diversity in this respect: it may hence happen that the longest body is the weakest, and it is probably to this circumstance we must attribute the popular notion of our mechanics, that a long rope is easier broken than a shorter one of equal quality and thickness. It is a fact perhaps drawn from experience, but it is one which cannot be introduced into the science of mechanics; for we must there suppose the body of uniform texture, and draw all our inferences from that source; and this obviously leads us to the above conclusion, *viz. the strength of bodies, exposed to strains in the direction of their length, is directly proportionate to their transverse area, whatever may be their figure, length, or position.*

As to the irregularities to which we have above alluded, they doubtless arise from a thousand circumstances, with which we are wholly unacquainted; in metals, it depends

upon their purity, the heat at which they are melted, the moulds in which they are cast, the manner in which they are left to cool, and many others, which totally escape our observation, since they produce different degrees of cohesion between particles, which, as far as our observation can extend, are circumstanced in every respect in the same manner, being all blended in one mass, and undistinguishable the one from the other.

It has been ascertained from experiment, that by forging a metal, or by frequently drawing it through a small hole in a steel-plate, its cohesion is considerably increased; a fact which, though it seems to have excited some astonishment, appears to us to be perfectly reconcilable with what might *a priori* have been expected from the increased density which this operation is known to produce. Admitting the particles to be placed at equal distances from each other, after wire-drawing or forging, as we suppose them to be before, their lateral distances will decrease as the cube root of their densities, and consequently the number that are brought in contact in equal sections, are as the 3d power of the density; the strength, therefore, ought to vary in the same ratio: as to the distances in the direction of the length, we do not conceive that it increases the strength; it may render the substance less liable to rupture in the first instance; but if, as in all probability is the case, the particles are ultimately removed to a greater distance before the fracture takes place, the same ultimate force will be requisite to separate the parts, however close the contact might be in the original state of the body; that is, when first submitted to the experiment.

We are unacquainted with the real increase of density that may be obtained by the processes above alluded to; and more particularly with the lateral approach of the particles, which may be greater than would arise from a uniform distribution of them; and are therefore unable to say how far the increased strength agrees with what we have hinted may arise from the increased contiguity of the particles. Lead, which is said to become rarer by wire-drawing, has its cohesion tripled; gold, silver, and brass, have also their cohesion nearly tripled; and copper and iron have theirs more than doubled. How far these facts can be satisfactorily explained by the greater contiguity of the particles *laterally*, we cannot pretend to say, but it certainly will account for a considerable part of the increased strength.

Experiments on the direct cohesion of all bodies, and particularly metals, are attended with considerable difficulty, in consequence of the enormous weights that are requisite for producing separation in bars of any considerable dimension: we have, however, a few results of this kind, which we owe to Muschenbroeck, and other experimentalists, the principal of which are contained in the annexed table, all reduced to the section of a square inch.

Metals.	Lbs.
Gold cast	20,000
	24,000
Silver cast	40,000
	43,000
Copper cast	19,500
Japan	22,000
Barbary	31,000
Hungary	34,000
Anglesea	37,000
Sweden	42,000
Iron cast	59,000
	65,000
Iron-bar	78,000
Ordinary	84,000
Stirian	71,000
Best Swedish and Russian	
Horse-nails	

		Lbs.
Steel-bar	{ Soft	120,000
	{ Razor-tempered	150,000
	{ Malacca	3,100
	{ Banca	3,600
Tin cast	{ Block	3,800
	{ English block	5,200
	{ English grain	6,500
Lead cast		860
Regulus of antimony		1,000
Zinc		2,600
Bismuth		2,900

It is very remarkable, that almost all mixtures of metals are stronger, or more tenacious, than the metals themselves, much depending upon the proportion of the ingredients, and these proportions are different in different metals. The following are some of those which Muschenbroeck asserts to produce the greatest strength.

	Lbs.
Two parts of gold with one of silver	28,000
Five parts of gold with one of copper	50,000
Five parts of silver with one of copper	48,500
Four parts of silver with one of tin	41,000
Six parts of copper with one of tin	41,000
Five parts of Japan copper with one of Banca tin	57,000
Six parts of Chili copper with one of Malacca tin	60,000
Six parts of Swedish copper with one of Malacca tin	64,000
Brass consisting of an unknown proportion of zinc and copper	51,000
Three parts of block-tin with one of lead	10,200
Eight parts of block-tin with one of zinc	10,000
Four parts of Malacca tin with one of regulus of antimony	12,000
Eight parts of lead with one of zinc	4,500
Four parts of tin with one of lead, and one of zinc	13,000

These results are very useful, provided they could be securely depended upon; but we could wish to see similar experiments repeated by other philosophers: not that we wish to undervalue the labours of Muschenbroeck, to whom the arts are much indebted for many valuable deductions, but so much irregularity takes place in experiments of this kind, that it is only in a multiplicity of them, complete accuracy, or even an approach towards it, is to be obtained.

The gun-founder might derive considerable information from a well-directed course of experiments of this kind, as well as the plumber and engineer: it appears from the above, that a mixture of copper, whose strength does not exceed 37,000 lbs., with tin, whose strength is 6000 lbs., a mixture is produced, whose strength is from 60,000 lbs. to 64,000 lbs., at the same time that it is harder, and easier wrought: and as to the objection that has been advanced against it, of being more fusible, we suspect it is nothing more than a false idea arising out of a very common error, that field-ordnance is liable to become fusible with rapid firing: we have been informed by very experienced artillery officers, that nothing of this kind ever happened, the damage which the piece sustains at the muzzle being merely due to the rubbing and knocking of the ball in its passage out of the gun.

Having said thus much with regard to the direct cohesion of metals, we must now attend to another very important subject; *viz.* the strength of timber.

The cohesion here is probably of a very different kind, and subject even to more inequalities than that of metals; much depends upon the soil where the tree grows, and a considerable difference is found between different parts of the same

tree; viz. whether it comes from near the root, or the top, or from the middle or sides; and even whether it grew on the north or south side.

1. The wood immediately surrounding the pith or heart of a tree, is said by some to be the weakest, particularly if the tree is old; others, especially Buffon, assert the contrary; the fact probably is, that up to a certain age it is strongest at the heart, but that afterwards these parts become weaker, or begin first to feel that decay which ultimately pervades the whole. In many experiments which we have made, we have always observed that the heaviest pieces (and there is a very considerable difference in this respect in different parts of the same tree) are the strongest; and, generally speaking, the part nearest the centre and towards the root has the greatest specific gravity.

2. The wood of the north side of all trees in our climates is said to be weaker than that of the south, and the south-east side the strongest: we are, however, much inclined to doubt the fact, as it relates to forest-trees. In trees particularly situated, with regard to exposure on one part more than another, something of the kind may have place; but trees in a forest, which experience very little difference in this respect, we are inclined to think, from some observations, have but little difference of strength depending upon their northern or southern direction. It is true, generally, that that wood is the strongest whose annual plates are thickest, the ligneous fibres being stronger than the trachea, or air-vessels; and, therefore, the more of the fibrous parts there are contained in any given dimension, the greater is the strength: but this is much more obvious in some woods than in others, and most of all, perhaps, in ash, in which we have seen a very remarkable difference in this respect. In very close-grained wood it is scarcely perceptible.

The only author who has enabled us to judge of the accuracy of his experiments is Muschenbroeck, who has described very minutely his apparatus, and his method of performing the experiments. The pieces he employed for this purpose were parallelepipeds, cut down in the middle to $\frac{1}{4}$ th of an inch square, or $\frac{1}{4}$ th of an inch section. These results, reduced to the section of a square inch, are as follow:

	Lbs.
Locust-tree - - - -	20,100
Jujeb - - - -	18,500
Beech oak - - - -	17,300
Orange - - - -	15,500
Alder - - - -	13,900
Elm - - - -	13,200
Mulberry - - - -	12,500
Willow - - - -	12,500
Ash - - - -	12,000
Plum - - - -	11,800
Elder - - - -	10,000
Pomegranate - - - -	9,750
Lemon - - - -	9,250
Tamarind - - - -	8,750
Fir - - - -	8,330
Walnut - - - -	8,130
Pitch-pine - - - -	7,650
Quince - - - -	6,750
Cypress - - - -	6,000
Poplar - - - -	5,500
Cedar - - - -	4,880

Emerson, in his *Mechanics*, gives us also a series of results, but they are unlike the former, as they do not exhibit the utmost strength, but what may be safely suspended on a square inch; yet as we may presume that each of those

weights are in the same proportion to the greatest strength, they ought to enable us, in some measure, to compare the relative strengths of the different woods given by these two authors. Emerson's table is as follows; viz.

	Lbs.
Oak, box, yew, plum-tree - - - -	7850
Elm, ash, beech - - - -	6070
Walnut, plum - - - -	5360
Red fir, holly, elder, plane, crab - - - -	5000
Cherry, hazel - - - -	4760
Alder, ash, birch, willow - - - -	4290

With regard to the absolute results in these two tables, we do not, in course, look for uniformity; the one exhibiting the ultimate strength, and the other the weight which a rod of an inch square may support with safety: but in the relative strength of the different woods, some coincidence might have been expected; we find, however, considerable difference in this respect. The latter author gives us no particulars, and we are therefore rather inclined to give the preference to the former, who has been very minute in his description, as well as careful in making the experiments; yet some subsequent experimentalists have not been able to find equal strength: thus M. Petit says, on the authority of his own experiments, and those of M. Parent, that the utmost strength of a square inch of oak does not exceed 8640 lbs.; whereas Muschenbroeck makes it 17,300 lbs.; and we must add, in confirmation of the former, that in the experiments to which we have before adverted, as at this time in progress at the Royal Military Academy, Woolwich, the strength of oak has been found but little exceeding 9000 lbs.; the specific gravity of it being 774. We have not this datum in either of the above cases; yet we conceive it to be a very important one, as we have always found the strength of wood of the same kind, to depend a great deal upon its weight or specific gravity. The same experiments give for the strength of ash 17,000 lbs., and fir from 10,000 lbs. to 13,000 lbs., both considerably different from Muschenbroeck's tabular results. The pieces from which these weights were found were cylindrical, very accurately turned to one-third and one-fourth of an inch in diameter; but to avoid any errors that might have place in gauging the diameters, their circumferences were taken by winding a fine silk thread ten times round them, and then dividing the length of it by 10 for the circumference.

On the Resistance of Bodies, when pressed longitudinally.—It is obvious that a body, when pressed endwise, by a sufficient force, may be crushed and destroyed; and this may take place, either by a total separation of the matter of which it is composed, or by bending it, whereby it is broke across: if the length or height of the body is very inconsiderable with regard to its other dimensions, the former is the almost certain result; but if its length be much more than its breadth and thickness, it generally bends before breaking, and in this case the operation is not very different from what takes place in beams supported at each end, and loaded in the middle; a subject which will be treated of in a subsequent part of this article. We have some very intricate analytical investigations on this subject by Euler and Lagrange. These authors have both treated the problem on the principles first promulgated by James Bernoulli, in his investigation of the properties of the elastic curve; but as we doubt very much whether they can be applied to any useful practical operations, we must beg to pass them over in this place, by merely referring such of our readers who are desirous of consulting the investigations of these two very able mathematicians, to the original works. Euler's first memoir will be found in the appendix to his "*Methodus*

inveniendi lineas curvas maximi et minimi, &c." 1744. A second memoir is published in the Berlin Transactions for 1757, and a third in the Acta Petro. 1778. Lagrange's papers are given in the Turin Memoirs for 1770-1, and in the Memoirs of Berlin for 1769.

As to the experiments that have been made on this kind of strain, there are few from which much practical information can be obtained. M. Petit says, that his experiments, and those of M. Parent, shew that the force necessary for crushing a body is nearly equal to that which will tear it asunder. He says that it requires something more than 60lbs. on every square line of sound oak to crush it. But experiments made on such small pieces cannot be depended upon; and when they are made on pieces of greater dimensions, the weights become so enormous, as to render them nearly impracticable; it is therefore fortunate that we have little occasion for very accurate information on this head: what it is more desirable to be acquainted with is, the resistance which a pillar or post will offer to compression before bending, the length being taken into consideration; for it is obvious, both from theory, as well as from a practical view of the subject, that the length of the beam must be an important datum in this kind of strain, although it is not in the former, viz. in opposing being drawn asunder; it is therefore very defective to state the requisite forces in both cases to be equal, or indeed to state any proportion whatever between them.

M. Girard, in his "Traité Analytique de la Résistance des Solides," Paris, 1798, details a great variety of experiments made on beams of fir and oak of considerable dimensions, by means of a certain machine constructed for the purpose. But as these experiments were not made so much with a view of breaking the pieces submitted to the pressure, as to measuring their deflections, and estimating what the author calls, after Euler, their absolute and relative elasticity; they do not furnish us with the kind of results above alluded to, as having been attempted by MM. Petit and Parent.

Through the whole course of M. Girard's experiments, much irregularity was observed, so much, indeed, as to render it very doubtful whether any number of experiments could furnish us with certain and conclusive results; and if experiments fail in this respect, it is wholly useless to look to any assistance from long and laborious analytical investigations. The following table contains many of the most important experiments of this author on oak-beams; the first column registers the number of the experiments; the second, third, and fourth, the length, depth, thickness, and weight of the beams; the fifth and sixth the distance of the greatest deflection from the bottom or foot of the beam; the former in the direction of the greatest thickness or depth; and the latter in the direction of the less thickness or breadth; the seventh and eighth columns contain the measure of the greatest deflection, or versed sine of the curve; the former of the depth, and the latter of the breadth; the ninth column exhibits the weights under which the several deflections were observed, and the tenth and last column the time between the first weight being applied and the observation. It should be observed, that M. Girard has given several more measures of deflections, weights, &c. than we have copied; we have, in all cases, taken his first two and last two, and omitted the intermediate ones.

The experiments marked with the * broke under the last registered weight; the others did not, and most of the latter

nearly recovered their original form after being unloaded for some hours. The deflections marked + and - are those in which the beam took a double curvature.

The other experiments of this author (the details of which occupy nearly 50 quarto pages) were made on the transverse strain, or rather on the deflection caused in beams by loading them in the centre with different weights, their extremities being supported on two props.

The oak-beams were the same which had been submitted to the longitudinal pressure, as exhibited in the following table, and which were not broken in those experiments; the third table contains the results of similar experiments on fir-beams of larger dimensions; and the two subsequent tables, similar ones on what the French workmen call *bois de brin*, that is, pieces which have been simply squared from the branches, or trunk, corresponding with what our workmen call *spars*.

In all these cases, the deflection was found to follow very nearly the ratio of the weights with which they were loaded, multiplied by the square of the length of the piece, and to be inversely as the square of the depth into the breadth. The fir-beams gave much more uniform results than those of oak, which is accounted for from the more regular and uniform organization of the former wood.

M. Girard endeavours to connect the results with those on the longitudinal pressure, for which purpose he gives us the following formulæ, viz. let f denote half the length of a beam, supported at each end and loaded in the middle, and let half that weight be denoted by P , and b the quantity of the beam's deflection; also π the semi-circumference of a circle, whose diameter is 1. then the

$$\text{absolute elasticity } Ekk = \frac{P f^3}{3b};$$

and the weight Q , under which the same beam will begin to curve, when pressed endwise, will be expressed by

$$Q = \frac{\pi^2 Ekk}{4f^2};$$

or, by substituting for Ekk , we have

$$Q = \frac{\pi^2 \cdot P \cdot f}{12b}.$$

We cannot, however, say how far this formula will apply, it being very difficult to ascertain the commencement of deflection in the actual experiment.

M. Girard gives us also two other formulæ, for estimating the deflection of oak and fir beams, when loaded in the middle by a weight, and supported at each end, viz.

$$\text{for oak } \frac{P f^3}{3b} = \frac{(11784451) (f + 0.3) a b^2}{1.3};$$

$$\text{for fir } \frac{P f^3}{3b} = (8161128) a b^2;$$

where P is half the weight, f half the length, b the deflection, b the depth of the beam, and a its breadth.

These apply only to rectangular beams; and, in order to render them general, the author uses the principles of Leibnitz, whereby the errors of the latter are connected with them in such a manner as to render the formulæ entirely useless for practical cases.

Girard's Experiments on Oak-beams, pressed in the Direction of their Length.

No. of Experiments.	Length in Metres.	Depth in Metres.	Breadth in Metres.	Weight in Kilograms.	Height of Deflection from the Foot in Metres.		Verified Sine of greatest Deflection.		Weight in Kilograms.	Time in Hours.
					In the Direction of its Depth.	In the Direction of its Breadth.	In the Direction of its Depth.	In the Direction of its Breadth.		
1	2.5979	0.1580	0.1285	54.7844	{ 1.0689 - - - -	{ 1.2989 - - - -	{ 0.0068 0.0090 0.0090 0.0113	{ - - 0.0068 0.0090 0.0090	{ 17,320 29,691 37,429 42,418	{ 0.83 2.08 2.91 9.58
*2	2.5979	0.1624	0.1060	44.0231	{ 1.1907 0.9742 - - - -	{ 1.2989 - - - - - -	{ 0.0056 0.0068 +0.0068 -0.0068	{ 0.0045 0.0079 0.0135	{ 11,993 25,664 42,514	{ 2.05 9.16 10.83
3	2.5979	0.1579	0.1015	42.0665	{ 0.6495 1.9484 1.7861 1.6237	{ - - - - - - - -	{ +0.0023 -0.0017 -0.0113 -0.0282	{ - - - - - - - -	{ 11,991 28,575 31,339	{ 0.83 9.58 10.41
4	2.5979	0.1330	0.0992	34.2402	{ 1.2989 1.2989 1.2989	{ 1.2989 1.2989 1.2989	{ 0.0113 0.0180 0.0479	{ 0.0079 0.0124 0.0124	{ 11,993 17,341 22,939	{ 6.66 8.33 10.0
*5	2.5979	0.1308	0.1060	33.2620	{ 1.2989 1.2989	{ 1.1366 0.9742	{ 0.0169 0.0372	{ 0.0068 0.0113	{ 11,996 17,341 22,931	{ 6.66 8.33 8.75
deflections not observed.										
6	2.2731	0.1556	0.1308	42.5557	{ - - 1.2989 1.2989	{ 1.1366 1.1366 1.2989	{ - - 0.0023 0.0023	{ 0.0028 0.0045 0.0034	{ 22,939 28,619 39,630 52,270	{ 6.66 9.58 18.33 22.50
deflections not observed.										
7	2.2731	0.1579	0.1285	45.9747	{ - - 1.6237 1.2989 1.2989	{ - - 0.9742 1.2989 1.2989	{ - - 0.0040 0.0169 0.0186	{ - - 0.0040 0.0045 0.0090	{ 17,317 22,934 47,047 47,032	{ 0.83 2.08 20.83 23.33
	2.2731	0.1556	0.1038	35.7076	{ 1.6327 1.6327 1.6327	{ 1.2989 1.2989 1.2989	{ 0.0062 0.0096 0.0181	{ 0.0034 0.0034 0.0045	{ 17,320 22,936 28,616 33,120	{ 12.08 12.91 13.75 13.95
deflections not observed.										
*9	2.2731	0.1579	0.1015	33.7511	{ 1.4613 1.2989	{ 1.2989 1.1366	{ 0.0068 0.0124	{ 0.0068 0.0045	{ 17,321 22,940 28,626	{ 12.08 12.58 14.50
deflections not observed.										
10	2.2731	0.1262	0.1015	30.3271	{ 1.4613 1.4613 1.4613 1.2989	{ 1.1366 0.9742 0.9742 0.9742	{ 0.0079 0.0079 0.0113 0.0135	{ 0.0062 0.0062 0.0062 0.0068	{ 11,999 15,025 17,320 20,326	{ 10.00 12.91 22.91 25.83

TABLE—continued.

No. of Experiments.	Length in Metres.	Depth in Metres.	Breadth in Metres.	Weight in Kilograms.	Height of Deflection from the Foot in Metres.		Verfed Sine of greatest Deflection.		Weight in Kilograms.	Time in Hours.
					In the Direction of its Depth.	In the Direction of its Breadth.	In the Direction of its Depth.	In the Direction of its Breadth.		
11	1.9484	0.1556	0.1330	44.5122	0.9742	0.9742	-0.0045	0.0079	17,321	7.08
					0.9742	0.9742	-0.0045	0.0090	22,940	10.00
					0.9742	0.9742	0.0034	0.0090	28,622	19.16
					0.9742	0.9742	0.0051	0.0101	33,105	26.66
12	1.9484	0.1579	0.1308	37.6642	0.9742	0.9742	0.0079	0.0130	22,940	20.00
					0.9742	0.9742	0.0079	0.0130	33,123	25.00
					0.6495	0.0146	+0.0068	0.0146	39,637	27.91
					1.6237		-0.0023			
13	1.9484	0.1579	0.1015	30.8362	0.6495	0.6495	0.0045	0.0056	17,321	2.08
					0.6495	0.6495	0.0062	0.0068	22,939	3.33
					0.6495	0.6495	+0.0068	0.0108	39,456	33.33
							-0.0023			
*14	1.9484	0.1601	0.1015	32.7728	1.4613	0.9742	0.0045	0.0040	11,973	10.00
					1.4613	0.9742	0.0045	0.0045	17,274	27.50
					1.6237	1.2989	0.0113	0.0090	28,509	37.50
					-	-	-	-	32,996	50.41
15	1.9484	0.1330	0.1060	28.3705	1.2989	0.6495	0.0056	0.0045	17,294	10.00
					0.9742	0.6495	0.0051	0.0045	22,899	28.33
					1.6237	1.4342	+0.0068	0.0118	46,952	86.66
					0.3247		-0.0011			
16	1.9484	0.1285	0.1082	26.9030	0.9742	0.9742	0.0045	0.0056	11,998	18.33
					0.9742	0.9742	0.0056	0.0079	17,317	20.00
					0.6495	0.6742	+0.0045	0.0135	37,273	92.50
					0.2435		-0.0011			
17	2.2731	0.1579	0.1082	35.7076	0.6495	0.9742	-0.0029	0.0028	11,998	10.00
					-	0.6495	-	0.0034	17,320	20.00
					1.6237	0.9742	0.0056	0.0045	33,120	52.50
					1.4613	0.9742	0.0113	0.0051	39,630	57.50
*18	2.5979	0.1579	0.1353	50.8712	0.9742	1.2989	0.0051	0.0034	11,999	10.00
					0.9742	1.2989	0.0068	0.0056	17,321	20.00
					1.9484	1.2989	-0.0079	0.0079	33,120	47.91
					1.6327	1.2989	-0.0146	0.0079	37,305	50.83
19	2.5979	0.1872	0.1579	72.8827	1.2989	-	0.0023	-	11,997	10.00
					1.2989	-	0.0034	-	17,318	20.00
					0.3297	1.2929	-0.0023	0.0056	62,513	110.0
					0.9742		+0.0023			
20	2.5979	0.1894	0.1579	65.5456	1.2989	-	0.0023	-	11,998	10.00
					1.2989	-	0.0023	-	17,321	22.91
					0.3247	1.6237	+0.0056	0.0101	62,534	122.0
					1.9484	1.6237	-0.0226	0.0135	62,468	212.0

The reader will perceive considerable irregularity in many of the above experiments, both with regard to the height at which the deflection begins, the quantity of it, and its direction; being sometimes in the line of the greatest thickness, and sometimes in that of the least, but more commonly in both. It will also be observed, that some of the beams broke under less pressures than others, of the same or less dimensions, bore without any apparent injury.

We cannot enter here into a farther explanation of the experiments, nor shall we attempt to illustrate the theory which the author seems desirous of establishing, both because it would carry us beyond our limits, and that, at the same time, we are very doubtful of its accuracy. When the only deduction is a mean drawn from a great variety of very irregular results, it is of little use to the practical engineer. He had much better be furnished with the several experiments, and thence form his own judgment of what dimensions will best suit his purpose, according to the particular object he may have in view; and in this respect, viz. in the detail of the experiments, rather than in theory deduced from them, we ought to estimate the value of this author's labours, which have been very great, and are deserving of high commendation.

The only experiments, besides the above, that appear entitled to any notice, are those of M. Ganthey, in the fourth volume of Rozier's *Journal de Physique*.

This engineer exposed to great pressures small rectangular parallelepipeds, cut from a great variety of stones, and noted the weights which crushed them. The following table exhibits the medium results of many trials, on two very uniform kinds of free-stone, one of them among the hardest, and the other among the softest, used in building.

The first column contains the length, the second the breadth, and the third the area, of the section, in lines, or twelfths of inches; the fourth is the weight in ounces which crushed them; and the fifth the whole numbers, which nearly expresses the number of ounces borne by each square line.

	Lines.	Lines.	Sq. lines.	Oz.	
Hard stone.	{		54	736	12
		12	96	2625	24
		16	128	4496	36
Soft stone.	{	9	16	144	560
		9	18	162	848
		18	18	324	2928
		18	24	432	5296

Very little can be deduced from these experiments. The first compared with the third, and the fifth with the sixth, should furnish similar results; for the first and fifth are respectively half of the third and sixth, but the third is three times stronger than the first, while the sixth is only double the strength of the fifth.

It appears, however, that the strength increases faster than the area of the section, and that a square line can carry more and more weight, as it is a part of a larger surface; but in the experiments on the soft stone, the strength seems to increase more nearly in proportion to the surface.

These experiments are doubtless upon too small a scale to be of any essential service to the practical engineer: the pieces of stone ought certainly to have had a square inch of surface at least, and the weight which would have been necessary to crush them would not have been so enormous, but that some very simple mechanical apparatus might have been made sufficient for the purpose; and if any tolerable uni-

formity were observed in pieces of that size, some useful conclusions might possibly be drawn from the experiments. But we think little confidence can be placed in those made on pieces of such small dimensions. According to M. Ganthey's deductions, a pillar of hard stone of Givry, whose section is a square foot, will bear with perfect safety 664,000 pounds; and its extreme strength is 871,000 pounds; and the least, as observed in his experiments, 460,000 pounds. The soft bed of Givry stone had for its least strength, on the same surface, 187,000 pounds; for its greatest, 311,000 pounds; and for its safe load, 249,000 pounds.

Good brick will carry with safety 320,000 pounds, on a square foot; and chalk, 9000 pounds.

Besides the above experiments on the force necessary for crushing stone pillars, M. Ganthey made others on their strength of direct cohesion, as well as on the transverse strain. He found that a prism of hard Givry stone, of a foot section, was torn asunder by a weight of 4600 pounds; and that, when firmly fixed in a horizontal wall, it will be broken by a weight of 56,000 pounds, suspended at the distance of twelve inches from its insertion; and if it rests on two props, a foot distant from each other, it requires 206,000 pounds laid on its centre to produce the fracture. We shall merely observe, that these results are very incongruous with each other; and that some mistake, or some very unaccountable irregularity, must have taken place in the experiments, that it should require so much more weight, acting at the distance of a foot, to produce the separation, than when the force acted at no mechanical advantage whatever, as in the case of direct cohesion.

Very different to the above have been the results of such experiments as we have performed on different kinds of wood. An oak rod of an inch surface requires a weight of about 9000 pounds to produce the fracture; while the same, or a similar rod, fixed in a wall, and acted upon at the distance of a foot, is broken with a weight of 132 pounds; and fir, which will bear 13,000 pounds on a square inch, suspended vertically, is broke with a weight of 136 pounds. We are aware that, in different materials, a different law may be observed between the strength of direct cohesion and the resistance of the same body to a transverse strain; but it is absolutely impossible to have the difference stated by M. Ganthey. A good course of experiments is, therefore, much wanted on materials of this kind.

We ought perhaps to observe, that we have not had an opportunity of consulting the work in which M. Ganthey's experiments were originally given. Our numbers are drawn from Dr. Robison's account of them, in the work to which we have before referred.

On the transverse Strain and Strength of Beams, &c.—The most usual strain, and, therefore, the one with which it is most important for us to be well informed, is that by which a body is broken across, from the action of a weight acting perpendicularly or obliquely to its length, while the beam itself is supported at its two extremities, or by one end being firmly fixed in a wall, or other solid and immoveable body. Galileo, to whom the physical sciences are so much indebted, was the first who connected this subject with mathematical principles, and endeavoured to trace the law of strength which different bodies possessed, in proportion to their length, breadth, depth, form, and position. It appears that this philosopher was led to these investigations, in consequence of a visit that he made to the arsenal of Venice, and the results of which were published in his *Dialogues* in 1633. Galileo supposed solid bodies to be

composed of small fibres applied parallel to each other, and sought, or assumed, at first, the force with which they resisted the action of a power to separate them, applied parallel to their length; and thence readily deduced that their resistance, in this direction, was directly as the area of the transverse perpendicular section, that is, to the number of fibres which compose the body. He then considered in what manner the same fibres would oppose a force applied perpendicular to their length; and concluded, that when a beam is fixed horizontally in a wall, the resistance of the integrant fibres is proportional to their sum, multiplied into the arm of a lever, which is always a certain part of the vertical dimension of the solid in its plane or area of fracture. This general principle is, in fact, adopted by most writers on this subject; but that which is peculiar to Galileo is, that he supposed the resistance of each fibre to be the same, and, therefore, as wholly independent of their quantity of extension at the moment of rupture. Supported on the result of these reasonings, and guided by the genius for observation, which he possessed in an eminent degree, he illustrated many of the proceedings of nature, which the more ancient philosophers had left unnoticed; as well as certain anomalies, or which then appeared as such, in the works of art. To some of his observations on this subject we may have occasion to advert, in a subsequent part of this article; but at present we shall confine ourselves to the illustration of his particular theory. It will be proper, however, first to define a few of the terms which more commonly occur in the course of our investigations.

We have already explained what is to be understood by the absolute strength of a body, or its strength of direct cohesion; *viz.* the number of pounds weight necessary to produce a fracture of its parts, when applied in a direction parallel to its length.

And as to the words *strength*, *stress* or *strain*, they are used, the former to denote the force or power with which any mass or body resists a breach or change in its state, which a pressure or stroke upon it has a tendency to produce; and the latter are used indiscriminately to express the force which is exerted on any such mass, and tending to break it. Thus, every part of a pillar is equally *strained* by the load which it supports; and hence it is evident that we cannot make any structure fit for its purpose, unless the *strength*, in every part, be at least equal to the *stress* laid on, or the *strain* exerted in that part; and hence the necessity of an acquaintance with the nature of the resistance of bodies, in order that we may not have our structure deficient in strength, nor over-burdened with useless materials; which latter, carried to excess, may be the cause of producing the mischief they were intended to prevent.

In order to illustrate the theory of resistances of bodies, when exposed to a transverse strain, according to the hypothesis of Galileo, let RSTV, (*Plate XXXIX. Mechanics, fig. 1.*) represent a solid wall, or other immovable mass, into which the beam, CG, is inserted; and let W represent a weight suspended from its other extremity. Then supposing the beam to be inflexibly strong in every part, except in the vertical section ABCD, the fracture must necessarily take place in this section only, and, according to the hypothesis of this author, it will turn about the line CD, whereby the fracture, commencing in the line AB, will terminate in the former, CD. Galileo also further supposes, that the fibres, forming the several horizontal plates or lamina from CD to AB, act with an equal force in resisting the fracture, and, therefore, differ in their energy only as they act at a greater or less

distance from the fulcrum CD. Now, from the known principles of the lever, it is obvious that the equal forces acting at the several distances *oa, ob, oc, od, &c.* of the lever *or*, will offer resistances proportional to their respective distances; and, therefore, that the sum of all these resistances, that is, of the constant force, *f*, of each particle into its respective distance, is the force which must be overcome by the weight W, acting at the distance *oK*.

This will, perhaps, be better understood by referring to *fig. 2*, where ACIF represent a section of the beam CG, and *r, r', r'', &c.* are so many small equal weights acting at the several distances *Cm, Cm', Cm'', &c.*; then denoting each of these weights by the constant quantity *f*, the sum of all their energies or resistances will be expressed by $AC \cdot f + Cm \cdot f + Cm' \cdot f + Cm'' \cdot f + \&c. = f \times (AC + Cm + Cm' + Cm'' + \&c.)$ This, however, supposes the section ACDB (*fig. 1.*) to be rectangular, or that the number of fibres in each horizontal lamina are equal in number. When the beam is triangular, cylindrical, or having any other than a rectangular section, the several small weights must be proportional to the breadth of the section at the point where it is supposed to act: the illustration, in this case, however, is equally obvious.

Since then the whole resistance to fracture is made up of the sum of the resistances of every particle or fibre acting at different distances on the lever CA, which is supposed to turn upon C as a fulcrum, there must necessarily be some point in that lever, in which, if all the several forces were united, their re-action to the weight W would be exactly the same as in the actual operation, and this point is the *centre of gravity of the section*, as is readily demonstrated as follows.

Let ABC (*fig. 3.*) represent the section of any beam whatever, FH any variable absciss = *x*, and DE the corresponding double ordinate = *y*; then, by what is stated above, the energy, or force, of all the particles in the line DE, will be as $DE \times HF$, or as xy , and consequently the fluxion of that force will be $y \cdot x \cdot \dot{x}$, and therefore the sum of them = $\int y \cdot x \cdot \dot{x}$, or fluent of $y \cdot x \cdot \dot{x}$ = area ABC; whence, assuming G to be the centre of energy sought, we must have $FG \times \int y \cdot x \cdot \dot{x} = \int y \cdot x \cdot \dot{x}$, whence

$$FG = \frac{\int y \cdot x \cdot \dot{x}}{\int y \cdot \dot{x}},$$

which is the well-known formula for the centre of gravity.

Hence results the following very simple theory for the strength of beams placed firmly in a solid wall, or other immovable body; *viz.* that "the weight necessary to produce the fracture, is to the direct force of cohesion of all the fibres in the section, as the distance of the centre of gravity of that section from the point where the fracture terminates, to the length of the beam, or distance of the weight from the same point."

Nothing more simple can be defined as a general theory, but unfortunately it is founded on hypotheses which have nothing equivalent to them in nature: in the first place, it assumes the beam to be inflexible, and insuperably strong, except at the section of fracture; secondly, that the fibres are inextensible and incompressible; and thirdly, that the beam turns about its lowest point, when fixed at one end, or its upper, when supported at both; and, consequently, that every fibre in the section is exerting its force in resisting extension; and, lastly, (if this be not implied in our second objection,) that every fibre acts with equal energy, whatever may be its quantity of extension. Now, with regard to the first of these suppositions, it is obvious that no beam of timber, nor any other body, is perfectly inflexible; nor

any (and more particularly timber) whose fibres are not both extensible and compressible; and, consequently, a beam of such matter will not turn about its lowest point as a fulcrum; and, lastly, the supposition of every fibre exerting a constant resistance, independently of its quantity of extension, if it be not incorrect, is of that nature which ought not to be assumed, without first being verified by experiment.

Such being the inaccuracy of Galileo's hypothesis, it necessarily happened, as soon as it was attempted to compare it with experiments, (which the author himself had never done,) that it was found defective. The first, we believe, who did this was Mariotte, a member of the French Academy in 1680; and what he published on the subject engaged the attention of many celebrated mathematicians of that day, particularly Leibnitz; who, after examining the theory of Galileo, published his own thoughts on the subject. He had frequently remarked that the rupture of a body, whatever it may be, is always preceded by a certain degree of inflection, from which he concluded, contrary to the former opinion, that every body was composed of extensible fibres, and assuming the principle first laid down by Dr. Hooke, viz. "ut tensio sic vis," he concluded that every fibre, instead of acting with an equal force, exerted a power proportional to its quantity of extension, or, which is the same, proportional to its distance from the line about which the beam was supposed to turn; but he still considered the fibres to be incompressible, and consequently that the beam turned about its lowest point. Thus, to use a similar illustration in this case that we have done in the former; instead of the fracture being opposed by the action of the equal weights at $r, r', r'', r''',$ &c. as in fig. 2, the re-action was supposed to be equal to the several equally decreasing weights $r, r', r'', r''',$ &c. fig. 4. The only alteration which this new supposition introduced into the final results was, the removal of the centre of energy, G, to a point nearer or farther from the centre of motion, according to the figure of the body; and this new point is found to be distant from that axis, by a quantity equal to the product of the distances of the centre of gravity, and centre of oscillation of the area of fracture, from the axis of motion, divided by the depth of the fracture.

For let ABC (fig. 3.) represent the section of fracture on any beam; FH = x , any variable abscissa; and DE = y , the corresponding double ordinate: also make CF = d , and let f represent the absolute and ultimate force of a fibre at C, in the moment of rupture; then, since the force of each fibre is supposed to vary as its extension, or as its

distance from F, we have $d : x :: f : \frac{fx}{d}$ = the force of a

particle at H; and the number of particles acting at this distance being y , we shall have $\frac{fxy}{d}$ for the sum of the

forces of all the fibres in the line DE; but this force, acting upon the lever at the distance HF, its resistance will be $\frac{fx'y}{d}$; and hence the sum of all the resistances of every

fibre in the section will be $= \int \frac{fyx^2 \dot{x}}{d}$: now this is to be equal to the direct cohesion of all the fibres acting at some required distance FI; that is, $FI \times fyx \times f = \frac{f}{d} \times$

$\int fyx^2 \dot{x}$, or $FI = \frac{1}{d} \frac{\int fyx^2 \dot{x}}{\int fyx}$: an expression which is exactly equivalent to the general expression $\frac{\int fyx^2 \dot{x}}{\int fyx}$, for the

centre of oscillation of a body, multiplied by $\frac{\int fyx \dot{x}}{\int fyx}$, the general expression for the centre of gravity, divided by d . Hence, as these centres are known in most bodies which come under our consideration in the present subject, it will be useful to avail ourselves of them in determining what may properly be called the *centre of energy*, or *centre of tension*.

This being the case, both theories gave the same results, so far as related to the comparison of the strength of similar beams, but of different dimensions; thus, from both, it was shewn, that beams of the same depth and breadth were to each other, in point of strength, inversely as the length; that when the length and depth were the same, the strength varied as the breadth; when the breadth and length were the same, the strength was directly as the square of the depths; deductions which have been found to agree very nearly with experiment. There were, however, some expressions arising out of these two hypotheses which were totally irreconcilable with each other. In the first place, although the proportions were the same, the absolute strength in the one case, was to that in the other as 2 to 3, in rectangular beams; and in triangular beams, the disagreement was still more striking: also, according to Galileo, the strength of a triangular beam, with its edge upwards, was to the same with its base upwards, as 1 to 2; and, according to Leibnitz, as 1 to 3: whereas, as we have found from numerous experiments, it is stronger in the former position than in the latter, at least in woods of some kinds, and probably in all.

These anomalies led James Bernoulli to investigate the question *de novo*. This philosopher observed, that at the instant a body is broken across by a transverse strain, such as we have all along supposed, a part of the fibres is in a state of extension, as assumed by Leibnitz, and a part in a state of compression, a circumstance which had not before been introduced into the consideration of the question: he moreover doubted of the propriety of the principle, *ut tensio sic vis*, employed by Leibnitz, and made some experiments, whereby he proved that this is not, at least, a general principle; but the only effect of his observations and experiments went no farther than proving that Leibnitz's theory was inadmissible, for he substituted no other in its place, except so far as his theory of the elastic curve (a problem which grew out of the present question) may be considered as applicable to this subject; had he pursued the idea he seems first to have promulgated, of a part of the fibres being compressed, and a part in a state of tension, and consequently that the line about which the beam turns is somewhere within the area of the section of fracture, we might have expected, from his extraordinary talents, a complete solution of this very interesting problem; instead of which, he contented himself with stating a few general observations, and pointing out the difficulty of the determination of the neutral axis, or of that line which suffers neither compression nor extension, which is the principal desideratum for establishing a correct theory; and in that state he left the question, and in that state it has ever since remained.

The only other attempt, that we know of, at establishing a new theory, is that given by Dr. Robison, under the article *Strength*, in the Encyclopædia Britannica. This

author has taken into his consideration the areas of compression and of extension; but for want of experiments, is unable to assign the position of the neutral axis: we suspect, also, an important error in the principle which he has laid down, *viz.* that notwithstanding the beam really turns about what he properly calls a neutral axis, yet that in our investigation, we must compute the effect of the rotation, as if it was made about the centre of compression. We were much struck with the singularity of this assertion, and have, we believed, proved its fallacy in various experiments.

There is no doubt, from various experiments, and particularly from those of Du Hamel, when a piece of timber is submitted to the transverse strain we are considering, that only a part, and probably but a small part, of the whole number of fibres, has a tendency to resist the fracture by means of their tension, while the rest of the fibres act merely from their resistance to compression. Du Hamel was, we believe, the first author who demonstrated the fact by experiment. He took sixteen bars of willow, two feet long, and half an inch square, and supporting them by props under their ends, he broke them by weights hung on their middle. Four of them broke with the weights 40, 41, 47, and 52 pounds, the mean of which is 45. He then cut four others of them through one-third of their depth on the upper side, and filled up the cut with a thin slip of harder wood, stuck in pretty tight. These were broken with weights of 48, 54, 52, and 50 pounds, the mean of which is 51. He then cut four others half through, and these required 47, 49, 50, and 46 pounds to break them, the mean of which is 48; the remaining four were cut to two-thirds of their depth, and their mean strength was 42 pounds.

In another set of his experiments we have the following results, *viz.*

Six bars of willow 36 inches long, and $1\frac{1}{2}$ inch square, were broken at a medium with 525 lbs.

Six bars cut one-third through, and the saw-cut filled up with a slip of hard wood, and stuck in tight, broke with 551 lbs. at a medium.

Six bars cut half through, and the cut filled up in the same manner, bore 542 lbs. before the fracture; and

Six others cut three-fourths through, broke with 530 lbs.

A batten cut similarly to the latter, that is to say, three-fourths through, when nearly broken, being unloaded, and a thicker slip put into the cut, in order to fill up the part which had been compressed, so as to bring the batten straight again, but without straining it, bore afterwards 577 lbs.

It will be remarked, that in these experiments the bars appear to have been stronger after being cut one-third through, than when whole; and even when cut half through, they still bore more than when they were entire. This seems to have arisen from the saw-cut being filled up with a harder wood, which rendered the beam stiffer than when in its natural state, by opposing a greater resistance to compression; and this may account for his beams being nearly as strong when cut three-fourths through, as when whole, as we have reason to believe, that there are very few woods, if any, in which the neutral line lay so near as within one-fourth of the bottom. We have made similar experiments on fir, and some other kinds of wood; and found that three beams of fir, 30 inches long, 2 inches deep, and 1 inch thick, broke with 882 lbs. 871 lbs. 852 lbs. respectively, the mean being 864 lbs. We then cut three other similar beams five-eighths through, and having filled up the cut with slips of pear-tree, found their strengths equal to 808 lbs.

846 lbs. and 835 lbs. of which the mean is 830 lbs.: these proved that the neutral line was nearer the bottom than three-eighths, because the pear-tree wedges, being softer than the fir, the deflection of the beams was throughout greater, which shew that they had lost in stiffness by the cutting; whereas Du Hamel's beams had gained stiffness from the circumstance of being filled up with wood harder than themselves: after all, however, this kind of experiment is not the best calculated for detecting the position of the neutral axis.

From what has now been stated, it is very obvious, that the theories both of Galileo and Leibnitz must be extremely defective, so far at least as they propose them to be employed in ascertaining the absolute strain that a beam will bear, when acted upon transversely by any weight, whether as supported at its ends, or by having one end fixed in a wall, as we have hitherto supposed. And as to the theory which Dr. Robison has advanced in the place above referred to, although it doubtless approaches much nearer to the truth, it is still, we conceive, incomplete; first, for want of experiments, from which alone the neutral axis can be determined; secondly, because he has not assigned the law of compression and tension, which is necessary for determining those centres in the section of fracture; and thirdly, because (as we have before stated) he supposes the rotation to be made about the centre of compression, instead of its being made about the neutral axis, and assigning the whole resistance to fracture to the extended fibres, instead of considering one half of it as due to compression and tension respectively. It is true that this may make no difference in the results, while we confine our investigation to rectangular beams, but it makes an important difference in triangular and other formed beams; in which cases, although it agrees better with experiment than the theories of either Galileo or Leibnitz, it is still very defective, as it gives greater strength to beams of a certain form, and in certain positions, where experiment shews them to be the weakest.

We cannot submit any of the formulæ of this author to computation, as they are merely general symbols, in which the indeterminate letters are to be supplied by numbers drawn from experiments; but in the two former, the expressions are determinate, and they may therefore be submitted to calculation, and the results compared with those that have been drawn from actual experiment; but before we proceed to this comparison, it will be proper to consider the relative strains that a beam is subject to, according to the manner in which it is supported; a consideration that is independent of any particular theory of resistances, and one in which different authors have come to very contradictory conclusions.

1. A beam having one end firmly fixed in a solid wall, will bear the same weight at its extreme end, as if the beam passed through the wall to the same length, and was loaded by an equal weight at its other end; its bearing in the wall being in the latter case supposed to be reduced theoretically to a line, and practically to such a bearing as will not damage the beam by cutting it. *Fig. 6.*

This will be evident to such of our readers who are conversant with the laws of motion, and who are familiar with the idea, that "action and re-action are equal and contrary;" but to others it may not be amiss to offer a few observations, by way of illustration.

Let A P C, and A' P' C', (*fig. 7.*) be two detached levers, supported on the props P, P'; and let us suppose their ends at C, C', to be held towards each other by a rope or cord

C C'. Now if we suppose the lever A' P' C' to be fixed by any means to the position shewn in the figure, while the other lever, A P C, is loaded with the weight W, and free to turn about P, the cord or fibre C C' will be stretched exactly in the same manner as the fibre at C (*fig. 6.*), when the beam is fastened solidly in the wall; and if, instead of supposing the first lever, A' P' C', to be fixed, we now suppose it loaded with a weight $W' = W$, and free to turn about P'; then the fibre C C' will be in all respects circumstanced like the fibre at C (*fig. 6.*), when the beam is supposed to pass through the wall, and a weight $W' = W$, acting in the direction A' I = A I.

But it is obvious that in *fig. 7.* the tension of the cord or fibre is the same in both cases; the only difference being, that the re-action of the fixed lever A' P' C', in the first instance, (and which is exactly equivalent to the force or energy of the weight W,) is, in the second, supplied by the action of an equal weight acting at an equal distance P' A'; and, consequently, whatever weight acting at the extremity is found sufficient to break a beam when firmly fixed in a wall, it will require an equal weight hung on at each end of a similar beam of double length, when resting on a prop in the middle, to produce the fracture.

2. And hence again it follows, that whatever weight will be just sufficient to break a beam when fixed solidly in a wall, a double weight will be required acting in the middle point, of a similar beam, of double length, supported on two props, as in *fig. 8.*: for it will be exactly the same as to the mechanical action, whether we consider the weight as acting at E, and the beam turning about P and P', or whether we suppose a fulcrum at E, and the beam turning about that point by means of weights W', W'', passing over the pulleys Q, Q, and each equal to half the centre-weight W, and the latter is evidently the same as the action of the weights W, W', *fig. 6.* only that they are acting in an opposite direction.

3. When a beam is loaded on any other point than its centre, and having its extremities resting on props, the strain upon it will be as the rectangle of the two unequal parts, and therefore the strain will be the greatest, or the strength of the beam the least, when the weight acts at its centre.

For let the weight W press upon the beam at C (*fig. 9.*) then is the weight equal to the pressures upon A and B;

and the pressure upon A = $\frac{W \times BC}{AB}$, while the pressure

upon B = $\frac{W \times AC}{AB}$; but the re-action of either point of

support is equal to the pressure upon it, and this may be considered as a force acting at the point C, as upon the arm of a lever; so that the stress at C, is as the pressure at either point of support into its distance from C, that is, the pressure

is as $\frac{W \times BC}{AB} \times AC$, or as $\frac{W \times AC}{AB} \times BC$, which are

manifestly equal the one to the other; but as W, and A B, are given, the stress varies as the rectangle; or if we suppose the ultimate strength of fibre the same, then W will vary inversely as the rectangle; and as the rectangle is the greatest when the parts are equal, therefore in the same case the strength of the beam will be the least.

The same thing will obtain, if the weight be equally diffused through the whole of the beam; for in this case, as in the former, the sum of the pressures upon A and B

will be equal to the whole weight; and if w be the weight

of the part B C, its pressure upon A will be $\frac{w \times \frac{1}{2} BC}{AB}$,

and this referred back to the point C, will give $\frac{w \times \frac{1}{2} BC}{AB}$

$\times AC$ for the stress, which therefore varies as the rectangle $BC \times AC$, as before.

4. When a beam is firmly fixed at both ends, as in two walls, or otherwise, the weight necessary to break it will be double of that which would produce the fracture if the ends were only supported.

Let A B C D (*fig. 10.*) represent a beam firmly fixed at each end, which is to be broke by a weight hanging upon its centre-point, as at E. Now, first let us suppose the beam cut through at E, so as to offer no resistance, and suppose the weight to be hung on so as to act equally upon the arms D E, C E, then W must be equal to double that which would break one part, as is obvious; and this is the same as would break the whole beam, when only supported at its ends by one prop, consequently when the beam is whole in the section E F, besides the weight W, which we have seen is necessary to overcome the resistances at D and C, an equal weight, W, must be added to overcome the equal resistance in the section E F; therefore the whole weight is equal to double that which would break the beam when only loosely supported at its two ends.

5. When a beam is fixed with one end in a wall, at any given oblique angle, the weight necessary to produce the rupture, is to the weight which would break the beam, if fixed horizontally, as radius to the cosine of the angle.

Let A B C D (*fig. 11.*) represent a beam fixed in a wall at the angle shewn in the figure; let D I be the vertical direction of the weight, and let this weight be represented by the line D I, and resolve this into the two forces D B and B I, the former perpendicular, and the other parallel to the beam A B; then it is obvious, that D B only will denote that part of the weight which is effective in producing the fracture, and that a weight which is to W, as D B is to D I, would break the beam when placed horizontally; therefore conversely, the weight necessary to break the beam in this position, is to that which would break it when fixed horizontally, as D I to D B; or as radius to the cosine of the angle of inclination of the beam to the horizon.

Most authors, indeed all we have ever read, make the strength in this case as the square of the radius to the square of the cosine; because the area of fracture is greater in the proportion of radius to cosine, which bleaded with the mechanical effect of the lever, gives $\text{rad.}^2 : \text{cos.}^2$; but the result of experiment by no means justifies such an hypothesis, nor does a physical consideration of the subject render it necessary, the number of fibres being the same in both cases.

We may now bring under one point of view the deductions drawn from the preceding propositions; *viz.*

1. The strength of a beam fixed with one end in a wall, and loaded at the other end, is to the strength of a beam of the same length, supported on two props, and loaded in the middle, as 1 to 4; or to a beam of double the length, loaded in the middle, as 1 to 2.

2. The stress upon a beam, arising from the same weight placed at different points, is as the rectangle of the two parts; and, therefore, the strength of the beam, or its resistance to fracture, will be inversely as the same rectangle; and,

consequently, the stress is the greatest, or the strength the least, when the load is placed in the centre.

3. The resistance to fracture in a beam *supported only* at its extremes, is to the resistance of the same when *fixed* at both ends, as 1 to 2.

4. The stress upon a beam, arising from any oblique action upon it, is as that force into the cosine of the angle; or the resistance will be in this case as radius to the cosine. These results are all independent of any particular theory of resistance, or rather, they form a part of every one; but they require certain modifications when applied to the determination of the absolute strength of beams. While they are merely used for ascertaining the proportional strengths, for the purposes of building, machinery, &c. they may be properly employed in the forms above given; it will be proper, however, to point out a few of the modifications to which we have alluded, as it will tend to clear up some apparent anomalies which have arisen in the experiments of M. Buffon, Belidor, Parent, Petit, &c.

In the first place, then, it will have been observed, that all our deductions have been made upon the supposition, that the beam preserves its rectilinear form and original position; and no account whatever has been taken of the deflection which it experiences from the horizontal or oblique line in which it is first supposed to be placed; nor is it necessary to attend to this circumstance while our views are carried no farther than determining the proper dimensions of timbers, in buildings, mechanical constructions, &c. because these are never submitted to strains that cause any important deflections; but when we attempt to reconcile theory with the result of experiments in which the beams are absolutely fractured, we must no longer omit the introduction of these particulars into our investigations.

Instead, therefore, of supposing a beam fixed at one end in a wall, and loaded at the other, to retain its horizontal position, as in *fig. 6*, we must consider it as being very considerably deflected out of that position, as in *fig. 12*; and if we here, for the sake of perspicuity, represent the resistance of the fibres to fracture by a weight *P*, it will be obvious that, in order that *P* and *W* may be in equilibrium, the weight *W* must be to the weight *P*, not simply in the inverse ratio of the arms *A I*, *A C*, but as these distances into the sines of their respective angles of directions; that is, as *A I* ×

$\sin. A I I' : A C \sin. A C Q :: P : \frac{A C \times P}{A I \times \sin. A I' I'}$
 $= W$ (because $\sin. A C Q = 1$); whereas our former result was $\frac{A C \times P}{A I}$; the weight therefore required to break

a beam in this position, is greater than what we found it to be in the case where no deflection was considered, in the ratio of the cosine of the angle of deflection to radius.

This is sometimes a very important quantity, as we have seen beams of three feet length, and two inches square, deflected twelve or thirteen inches, that is to say, to the amount of one-third of their length, or 20° : and the cosine of 20° is to radius as 93 to 100.

The reverse of this happens when a beam is loaded in the middle, and supported at its extremities on two props; for in this case the re-action of the props is not made, as we have supposed, in a direction opposite to the vertical action of the weight, but perpendicular to the arms of the lever. The beam *A B C D* (*fig. 13*.) is therefore kept in equilibrium with regard to its strain, by the action of three forces, *viz.* the weight *W*, the quantity and direction of which may be denoted by the diagonal *S G*, *viz.* the diagonal of the parallelogram, of which *P S*, *P S*, are two adjacent sides, and

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which equally denote the quantity and direction of the re-action of the props: which will therefore be greater than $\frac{1}{2} W$, the quantity we have supposed in our former investigation, in the ratio of *S P* to *S F*; that is, in the ratio of radius to the cosine of the angle of deflection.

Hence it appears that when a beam is fixed at one end, and the computed weight necessary to break it be *W*, the

real weight that must be employed will be $\frac{W}{\cos. D}$; *D* de-

noting the angle of deflection: but when the beam is supported at both ends, and the computed weight *W'*, and the angle of deflection *D'*, then the real weight will be $W' \cos. D'$.

Hence, supposing the former beam to have the same breadth and depth, but only half the length of the latter; we shall have, according to the preceding theory, $W : W' :: 1 : 2$, whereas, from this modification of it, the analogy is $W : W :: 1 : 2 \cos. D$. $\cos. D'$, which (if the beams are small in proportion to their length, as was the case with those of M. Parent) is quite sufficient for reducing the ratio to 2 : 3 or 4 : 6, as found by that author.

Again, with regard to a beam having its two ends solidly fixed, its strength, according to our preceding investigation, as compared with an equal beam supported at both ends, is as 2 : 1; but this supposes the three fractures to take place at the same time, or that the same deflection that is necessary for producing the fracture at *F* (*fig. 10*.) will also at the same time cause the fracture to happen in the two sections *D A*, *C B*; but this, like the preceding, will not apply to the ultimate result; as the deflection of the half beams *A F*, *B F*, is found in experiment to be nearly double that of the whole beam *A B*; and therefore, supposing the deflection to be as the weight, as it is in fact very nearly for a considerable time, it will only require, in addition to the weight that would break the beam, when supported at its ends, such a weight as would produce the deflection in the half beams, equal to that at which the supported beam breaks; that is, about half the said weight; and, consequently, the ratio of the strength of the fixed beam to that which is merely supported, instead of being as 2 to 1, will be reduced to that of 3 to 2, or 9 to 6, as found in the experiments above referred to, as well as in those of Belidor, as published by him in his "Science des Ingenieurs." M. Parent found that a beam supported at one end only in a wall, and another of double length supported at both ends, and an equal beam fixed at both ends, broke with weights which had very nearly the proportion of 4, 6, and 9; whereas the theory, which takes no account of deflection, gives 4, 8, 16; but what is stated above, shews that Parent's numbers are those which ought to be found by experiment; and the same explanation renders the results in the following table of Belidor also perfectly reconcilable with each other.

We have also, since the above was written, made several experiments of the same kind, in order to compare the strength of beams according to the manner in which they were supported or fixed, at one end or both; and according as they were fixed horizontally, or at different angles of inclination; and in all those cases the results answer very nearly to what the preceding theory requires. Thus a beam of fir six feet long and two inches square, supported at each end, broke with 744 lbs.; and the mean of several experiments on similar pieces of the same dimension fixed at each end, require 1105 lbs.; and the fragments of the same, three feet long, broke with one end in a wall, required at a medium 400 lbs.; the ratio of which numbers are not very different from those above stated.

Y y

Belidor's Experiments.—These pieces were found even-grained oak; the column *b* contains the breadth, *d* the depth, and *l* the length, all in inches: *p* shews the number of pounds which broke them, and *m* the mean weight, also in pounds.

N ^o	<i>b</i>	<i>d</i>	<i>l</i>	<i>p</i>	<i>m</i>	How fixed.
1	1	1	18	400 415 405	406	the ends lying loose.
2	1	1	18	600 600 624	608	the ends firmly fixed.
3	2	1	18	810 795 812	805	the ends loose.
4	1	2	18	1570 1580 1590	1580	the ends loose.
5	1	1	36	185 195 180	187	the ends loose.
6	1	1	36	285 280 285	283	the ends fixed.
7	2	2	36	1550 1620 1585	1585	the ends loose.
8	1½	2½	36	1665 1675 1640	1660	the ends loose.

By a comparison of these results, we find

1. From a comparison of experiments 1 and 3, that the strength is proportional to the breadth.
2. Experiments 3 and 4 shew that the strength is proportional to the square of the depth.
3. Experiments 1 and 5 shew the strength to be nearly in the inverse ratio of the length.
4. Experiments 5 and 7 shew the strength proportional to the breadth and square of the depth.
5. Experiments 1 and 7 shew, by combination, that the strength is in the ratio of the area of fracture into the depth, and in the inverse ratio of the lengths.
6. Experiments 1 and 2, as also 5 and 6, shew that the strength of beams fixed at both ends is to that of those which are only supported in the ratio of 3 : 2.

ave shewn that this last proportion is about what

ought to result from experiments; although no theory that we know of introduces this consideration.

Another discrepancy between theory and experiment is, where the strength ought to be inversely as the length, it shews itself in the above experiments, but is very remarkable in those of M. Buffon; and though our preceding remarks will explain very satisfactorily this deviation, we are almost afraid to offer it as an illustration; after seeing it treated as an inexplicable paradox by some writers of the first eminence: Dr. Robison, for example, says, "the engineer will carefully keep in mind the important fact, that a beam of quadruple length, instead of having $\frac{1}{4}$ th of the strength, has only about $\frac{1}{16}$ th; and the philosopher should endeavour to discover the cause of this diminution, that he may give the artist a more accurate rule of computation."

In another place he attempts to account for it from physical considerations, viz. that the trees being strongest at the root end: Buffon's longest pieces were broke in the weakest part, which however does not appear quite certain, as we cannot tell from which end his shortest pieces were cut; he also thinks, that the curvature being greatest in the longer pieces, may also be a cause of the deficiency above alluded to. We are not disposed to deny that these may both have an influence; but it certainly appears to us, that instead of looking for a physical explanation, what we have before remarked with regard to the deflection is quite sufficient to account for the anomaly on pure mathematical principles. We have seen, that if *W* be the computed weight, independent of deflection, the absolute weight will be *W* cos. *D*, *D* being the angle of deflection; and as this deflection, both from theory and practice, is found to increase as the square of the length; it follows, that when the length is quadrupled, the depth of deflection will be sixteen times greater; that is, the sine of the angle of deflection will be sixteen times more in one case than in the other, while the radius will be only four times longer; and therefore, the angle is in one case about four times what it is in the other, (supposing in a rough way the angle to vary as the sine). Consequently, if $W \times \cos. D$ is the weight which breaks the shorter beam, $\frac{1}{4} W \times \cos. 4D$ ought to be that which breaks the longer one; and this we presume will nearly, if not entirely, account for the decrease of strength in Buffon's experiments. We cannot perceive but that this reasoning is perfectly legitimate, yet we are astonished that it should not have occurred to so keen a mathematician as the one to whom we have alluded, or to some one of the writers on this subject, and on this account we offer it with some hesitation.

The following table contains the result of Buffon's experiments, which are by far the most valuable of any that have yet been made, both on account of the number of them, and the size of the beams that were employed. The dimensions are given in metres, and the weights in kilograms, as reduced by M. Girard, except that we have not always retained the same number of decimals; these may be reduced to English measure by observing, that 1 metre = 3.281 English feet, and 1 kilogram = 2.20652 lbs. avoirdupois.

TABLE of Buffon's Experiments on the Strength of Square Oak-beams, supported at both Ends.

No. of Experiments.	Side of the Square.	Length of the Piece.	Weight of the Piece.	Weight which it bore before it broke.	Deflection before the Fracture.	Time from the first Fracture to the final Rupture.	Deflection at the instant of Rupture.	Lengthening or stretching of the Fibres to a Metre in Length.	Mean stretching of the Fibres.
	Metres.	Metres.	Kilog.	Kilog.	Metres.	Hours.	Metres.	Metres.	Metres.
1	0.1082	2.2732	29.34	2616	0.0946	0.2013	0.1217	0.005	
2		2.2732	27.39	2580	0.1217	0.1527	0.1758	0.011	
3		2.5979	33.26	2250	0.1013	0.1041	0.2164	0.013	
4		2.5979	30.81	2201	0.1262	0.0902	0.2976	0.026	
5		2.9227	37.66	2005	0.1307	0.0972	0.2029	0.009	
6		2.9227	34.72	1932	0.1488	0.0833	0.2435	0.013	
7		3.2473	41.08	1773	0.1578	0.1041	0.1758	0.005	
8		3.2773	40.10	1760	0.1758	0.1041	0.1758	0.004	
9		3.8969	48.91	1491	0.1894		0.1894	0.004	
10		3.8969	47.93	1430	0.1894		0.2164	0.006	
11		2.2732	45.97	5759	0.0676	0.4027	0.0968	0.003	
12		2.2732	43.33	5515	0.0676	0.3819			
13		2.5979	50.87	4842	0.0721	0.2777	0.1353	0.005	
14		2.5979	49.89	4732	0.0789	0.2708	0.1239	0.004	
15		2.9227	57.71	4108	0.0811	0.1944	0.1623	0.006	
16		2.9227	56.74	4072	0.0878	0.1944	0.1443	0.004	
17		2.9227	56.25	4010	0.0946	0.1805	0.1353	0.004	
18		3.2473	64.56	3534	0.0856	0.1458	0.2029	0.007	
19		3.2473	63.59	3448	0.0946	0.1388	0.1825	0.006	
20		3.2473	62.85	3472	0.1082	0.1944	0.2321	0.010	
21	0.1353	3.8969	76.30	2959	0.1488	0.2083	0.3517	0.016	0.0074452
22		3.8969	75.32	2983	0.1556				
23		4.5464	87.06	2641	0.2164		0.2706	0.007	
24		4.5464	86.08	2543	0.2231	0.1250	0.3517	0.011	
25		5.1959	102.23	2164	0.2186	0.1180	0.4328	0.013	
26		5.1959	100.27	2091	0.2209	0.1041	0.4906	0.017	
27		5.8453	113.48	1834	0.2164	0.0763	0.4599	0.012	
28		5.8453	112.99	1499	0.2209	0.0694	0.4058	0.009	
29		6.4946	129.64	1601	0.2389	0.0694	0.4373	0.009	
30		6.4946	126.68	1553	0.2706	0.0555	0.5547	0.014	
31		7.1440	137.45	1455	0.3043	0.1250	0.5141	0.010	
32		7.7939	151.63	1076	0.2976	0.1111	0.4058	0.005	
33		7.7939	150.16	1039	0.3652	0.1041	0.4328	0.006	
34		9.0928	178.04	880	0.4870	0.1180	0.6768	0.011	
35		9.0928	166.09	885	0.5952	0.1180	0.7576	0.013	
36	0.1624	2.2732	62.8551	9416					
37		2.2732	58.9373	9122					
38		2.5979	72.8827	7679	0.0631	0.7568	0.1353	0.005	
39		2.5979	71.4152	7508	0.0653	0.6804	0.1127	0.011	
40		2.9227	81.1982	6579	0.0676	0.4999	0.1398	0.013	

TABLE — *continued.*

No. of Experiments.	Side of the Square.	Length of the Piece.	Weight of the Piece.	Weight which it bore before it broke.	Deflection before the Fracture.	Time from the first Fracture to the final Rupture.	Deflection at the instant of Rupture.	Lengthening or stretching of the Fibres to a Metre in Length.	Mean stretching of the Fibres.
	Metres.	Metres.	Kilog.	Kilog.	Metres	Hours.	Metres.	Metres.	Metres.
41	0.1624	2.9227	80.4644	6285	0.0766	0.3541	0.1353	0.026	0.0074452
42		3.2473	91.9594	5612	0.0811	0.3194	0.2164	0.008	
43		3.2473	90.9911	5392	0.0946	0.3055	0.1623	0.004	
44		3.8969	109.5689	4500	0.1082	0.2152	0.1894	0.004	
45		3.8969	108.1012	4402	0.1107	0.2222	0.1578	0.003	
46	0.1624	4.5464	124.7322	3644	0.1217	0.1736	0.2706	0.007	
47		4.5464	124.2431	3668	0.1107	0.1527	0.3066	0.009	
48		5.1959	143.8087	3057	0.1188	0.1388	0.2164	0.003	
49		5.1959	143.3197	3167	0.1578	0.1319	0.2706	0.005	
50		5.8453	163.3747	2751	0.2006	0.1111	0.5952	0.020	
51	0.1894	5.8453	161.9073	2690	0.2299	0.0972	0.2706	0.004	
52		6.4946	184.4080	2457	0.2570	0.0833	0.5600	0.014	
53		6.4946	183.4297	2384	0.2389	0.0763	0.3788	0.006	
54		2.5979	99.78	12791	0.0743	0.8749	0.1082	0.003	
55		2.5979	99.78	12693	0.0676	0.9235	0.1013	0.003	
56	0.2165	2.9226	111.03	11152	0.0836	0.6943	0.1488	0.005	
57		2.9226	110.05	10712	0.0789	0.6735	0.1398	0.004	
58		3.2473	124.24	9611	0.0689	0.5068	0.3519	0.023	
59		3.2473	123.25	9440	0.0811	0.5277	0.2435	0.011	
60		3.8969	147.72	8217	0.0789	0.4374	0.2029	0.005	
61	0.2165	3.8969	147.23	7606	0.0900	0.4166	0.1894	0.004	
62		4.5464	173.64	6652	0.1127	0.3816	0.1961	0.003	
63		4.5464	171.69	6285	0.1013	0.3333	0.2186	0.004	
64		5.1959	198.59	5429	0.1307	0.2847	0.2706	0.005	
65		5.1959	197.12	5331	0.1420	0.2500	0.3088	0.007	
66	0.2165	5.8453	222.07	4622	0.1488	0.1875	0.3246	0.006	
67		5.8453	222.07	4597	0.1578	0.1527	0.2570	0.003	
68		6.4946	247.01	4182	0.2119	0.1041	0.3403	0.005	
69		6.4946	247.50	3913	0.2299	0.0902	0.3246	0.004	
70		3.2473	161.90	13598	0.0811	0.1805	0.1555	0.004	
71	0.2165	3.2473	161.90	13041	0.0608	0.2360	0.1194	0.002	
72		3.8968	194.19	11190	0.0811	0.6249	0.1660	0.003	
73		3.8968	193.45	10750	0.0789	0.5763	0.1803	0.004	
74		4.5464	225.49	9807	0.1036	0.4582	0.2299	0.005	
75		4.5464	224.51	9538	0.0856	0.4304	0.2164	0.004	
76	0.2165	5.1959	256.80	8217	0.1398	0.3263	0.2706	0.005	
77		5.1959	256.31	7801	0.1013	0.3472	0.2016	0.003	
78		5.8453	290.55	6603	0.1217	0.2222	0.2751	0.004	
79		5.8453	290.06	6309	0.1104	0.2083	0.2096	0.002	
80		6.4946	323.79	5759	0.1758	0.1666	0.2976	0.004	
81		6.4946	322.83	5967	0.1623	0.1944	0.2605	0.002	

It remains now for us to offer a few observations with regard to the relation between the strength of direct cohesion, and the strength of beams submitted to transverse strains; but, unfortunately, we have very little on which to rest any theory in this respect. We know of no experiments that have yet been made with a view to this determination, except those to which we have above referred, as being at present in progress at the Royal Military Academy, and these are not yet sufficiently forward to enable us to offer any decided theory.

According to Galileo's theory, if f denote the strength of direct cohesion, that is, the number of pounds necessary to break a bar of one inch square; a the area, in inches, of the section of fracture; d the depth of its centre of gravity from the edge about which the beam is supposed to turn; and l the length, also in inches; and W the required weight; then

1. When the beam is fixed with one end in a wall,

$$W = \frac{f a d}{l}.$$

2. When the beam is supported at both ends, then

$$W = 4 f a d$$

3. When the beam is fixed at both ends,

$$W = \frac{8 f a d}{l}.$$

The weight in both the latter cases being supposed to rest on the middle of the beam, and in the first at its end. When the weight acts at any other part of the beam, the stress varies directly as the rectangle of the two parts, or the strength is inversely as the same.

According to Leibnitz's theory, if a is the area, l the length in inches, and f the strength of direct cohesion in pounds, on a square inch, as before; also D the depth of the section of fracture, Δ the distance of its centre of oscillation, and d that of its centre of gravity from the point about which the beam turns; then,

1. When the beam is fixed at one end,

$$W = \frac{f a \Delta d}{l D}.$$

2. When the beam is supported at both ends,

$$W = \frac{4 f a \Delta d}{l D}.$$

3. When the beam is fixed at both ends,

$$W = \frac{8 f a \Delta d}{l D}.$$

From these general theorems it is usual to draw a variety of corollaries as to the strength of beams of different forms, and in different positions. Thus, from the former, it appears that a triangular beam, fixed with one end in a wall, with its edge downwards, or supported at its two ends, with its base downwards, has double the strength of an equal beam laid the contrary way, *i. e.* with its base down in the first case, and upwards in the second; and Leibnitz's formula makes the strength three times as much; whereas experiment proves that the beam is weaker in both these cases, stronger, according to their theory, it should be so much stronger.

Similar erroneous conclusions are also drawn from these theorems, with regard to hollow cylinders, not bored through the axis, but on one side of it; the strength, ac-

cording to the above, being greatest when the beam is made to turn about the thinnest part: but here, again, experiment shews it to be weakest in that position.

With regard to the hollow cylinder bored through its axis, the above theorems, though they are still inaccurate with regard to the proportion between the direct cohesion and the transverse strain, are not much out in respect to the proportional strength, according to the size of the bore, and the thickness of the sides: in fact, both sets of theorems give the same results, with regard to the proportional strengths, as depending upon the lengths, depths, breadths, &c. of the beams, while these remain of the same form, and rest in the same position; it is in the comparison of different formed beams with each other, or different positions of the same beam, where the defect is the most obvious; and particularly with regard to *all beams*, as depending upon the strength of direct cohesion. On this account, we shall dispense with the corollaries and deductions above referred to, as being more likely to mislead than to instruct the engineer, although we thought it right to mention them; and if we cannot supply them with well established rules and formulae, we will at least endeavour to point out how such may be obtained.

We have already stated that the beam, instead of turning about the line CD (*fig. 1.*), as supposed by Galileo and Leibnitz, really turns about a line within the area of fracture, as shewn by the section, *fig. 5*; *viz.* instead of turning about the lower point C , the beam will turn about some other line, represented in the figure by n , the situation of which is unknown, but whose position is absolutely necessary to be determined, in order to establish a correct theory of the strength of beams. According to Du Hamel's experiments on willow, it is at about one-third the depth from A ; and those that we have made, make it about the same for fir: and though there may be some difference in this respect, in woods of different kinds, it is probably not far from that point in any.

Now all the fibres between n and A are those only which are in a state of tension; the others between n and C being in a state of compression; while the fibres in the line, of which the section is n , will be neither compressed nor stretched; on which account this is commonly called the *neutral line*, or *neutral axis*. Hence we see, that in the theories of Galileo and Leibnitz, the strength of beams, as deduced from the strength of direct cohesion, must far exceed the real strength, not more than one-third of the fibres, which they suppose, being employed to resist the fracture at least by tension; also the centre of tension being at only one-third of the distance they have assumed, these combined would make the real strength only one-ninth of the computed strength. But as we may suppose that exactly one-half of the entire force is employed in producing the compression, that is, that the beam turns about that point where the resistance to compression is equal to that of tension, this reduces it to $4\frac{1}{2}$ times; that is, the computed strength is about $4\frac{1}{2}$ times greater than it would be, if the neutral line were, as we have supposed, at one-third of the depth from the upper surface of the beam.

This defect is common to both these authors, after conceding to each his own particular law of tension; that is to say, to Galileo, that every fibre acts with the same energy; and to Leibnitz, that the tension is as the force. But one or both of these suppositions must be erroneous; and we must say, that, independent of experiments, we should certainly have been inclined to adopt the latter; but we are convinced, from a great multiplicity of results, that Galileo is much nearer, if not exactly conformable to the actual

operation. However difficult it, therefore, may be to account for this equality in the force of tension on physical principles, we must adopt it as a fact deduced from experiment, and leave to the philosopher the explanation of its existence.

Our limits will not admit of reporting here the nature of the experiments, nor the calculations founded upon them, which led to this determination; but we hope soon to see them laid before the public in another form. We can only give here the result, which, as far as it is at present ascertained, is as follows:

The centre of tension and centre of compression are nearly or exactly coincident with the centre of gravity; and the neutral line, whatever may be the figure of the section, is so posited, that the rectangle of the area of tension into the distance of its centre of gravity from the said line, is to the rectangle of the area of compression into the distance of its centre of gravity as 1 to 3.

From which theorem, the neutral line for any formed beam may be determined, and the absolute strength may then be found as follows, viz.: Let d denote the distance of the centre of tension from the neutral line, a the area of tension, and l the length of the beam, all in inches; D the angle of deflection, and f the strength of direct cohesion on a square inch; then, without considering the increased length of lever,

1. When the beam is fixed at one end,

$$W = \frac{2fad}{l \cdot \text{cof. } D}.$$

2. When the beam is supported at both ends,

$$W = \frac{8fad}{l} \times \text{cof. } D.$$

3. When the beam is fixed at both ends,

$$W = \frac{12fad}{l} \text{ col. } D.$$

And when the beam is fixed at one end at any angle, formula (1) will still apply; only increasing or decreasing the angle of deflection by the quantity of the first angle of inclination, according as that inclination is downwards or upwards.

And when the beam is supported, or fixed, at both ends, and either resting obliquely, or acted upon by an oblique force; the two latter formulæ become,

4. For the beam supported at each end,

$$W = \frac{8fad}{l} \times \frac{\text{cof. } D}{\text{cof. } I}.$$

5. For the beam fixed at each end,

$$W = \frac{12fad}{l} \times \frac{\text{cof. } D}{\text{cof. } I}.$$

Where I denotes the angle which the direction of the force makes with the direction of the beam.

Note 1. It should be observed that the preceding theorem, for determining the neutral line, is principally drawn from experiments on fir-beams. A different ratio than 1 : 3 may be necessary in other kinds of wood; but at present that ratio has not been found.

Note 2. The deflection D , as we have before observed, is not a necessary datum in estimating the strength of timber, for any practical purposes of building, &c.: it is merely introduced in order to reconcile theory with the result of experiments made upon the absolute and ultimate strength;

in which cases, particularly in long beams, it becomes an important quantity, and must not be omitted; and in all cases where it is required, it must be drawn from some prior experiment on the same kind of wood, by means of the following theorem, viz.

Let $l, d,$ and D , represent the length, depth, and deflection of any beam; and l', d' the length and depth of any other beam, whose deflection D' is required; then,

$$D' = \frac{l' d D}{l d'}.$$

See the several works referred to in the beginning of the article, by Bernoulli, Euler, Lagrange, &c.

We shall now illustrate these theorems by a few examples

Example 1.—The strength of direct cohesion on a square inch of fir being 13,000 lbs., required the weight necessary to break a rectangular bar 30 inches long, 2 inches deep, and 1 inch in breadth; when fixed at one end in a wall, and the weight acting at the other; the deflection, computed from other experiments, having been found to be 5 inches.

First, to find the neutral line: here, since the section is a rectangle, the centres of tension and compression are each on the centres of their respective areas; therefore, call the depth of tension x , the depth of compression will be $2 - x$, which also denote these areas; and we must have, therefore,

$$\frac{x^2}{2} : \frac{(2-x)^2}{2} :: 1 : 3;$$

$$\text{or } 3x^2 = 4 - 4x + x^2; \text{ or } x^2 + 2x = 2.$$

$$\text{Whence } x = -1 + \sqrt{3} = .732 = a;$$

$$\text{also } \frac{.732^2}{2} = .366 = d;$$

$$\tan. \text{ of deflection} = \frac{5}{30} = .16666666.$$

Whence the angle $D = 9^\circ 34'$, and its cosine = .9860; therefore, by formula 1,

$$W = \frac{2fad}{l \cdot \text{cof. } D} = \frac{2 \times 13000 \times .732 \times .366}{30 \times .986} = 235 \text{ lbs.}$$

Example 2.—Required the weight that would break the same beam when supported at each end, rejecting the deflection, which is very inconsiderable.

By formula 2,

$$W = \frac{8fad}{l} = \frac{8 \times 13000 \times .732 \times .366}{30} = 928 \text{ lbs.}$$

Example 3.—Required the weight that would break the same beam fixed at each end.

Rejecting the deflection, we have from formula 3,

$$W = \frac{12fad}{l} = \frac{12 \times 13000 \times .732 \times .366}{30} = 1492 \text{ lbs.}$$

Note.—We have here assumed 13000 for the force of direct cohesion; this, however, rather exceeds the greatest strength of fir, which varies from 10000 to about 13000 lbs.

Example 4.—Assuming the direct cohesion at 13000, and the specific gravity of fir 720; how long must a beam be that is two inches deep, and one inch broad, which, fixed with one end in a wall, will just break with its own weight?

Let x be the required length of the beam, in inches; its

weight will be $\frac{2x \times 720}{1728}$ ounces, or $\frac{90x}{1728} = \frac{5x}{96}$ pounds;

and this weight will have the same effect as if it acted all at one point in the centre of the beam, or at the distance $\frac{1}{2}x$.

Hence, by substituting $\frac{5x}{96}$ for W in formula 1, we have

$$\frac{5x}{96} = \frac{2 \times 13000 \times .732 \times .366}{\frac{1}{2}x},$$

or $5x^2 = 192 \times 2 \times 13000 \times .732 \times .366 = 133728$.

Whence $x = \sqrt{\frac{133728}{5}}$ inches, or 47 feet. In this

case, the angle of deflection is not introduced.

When the deflection is considered, as it should be in this case, we find it to be from the data of example 1, and the

theorem for the deflection, as $30^2 : 5 :: \frac{1}{4}x^2 : \frac{5x^2}{3600}$.

Whence the cosine = $\sqrt{\left(1 - \frac{25x^2}{1800^2}\right)}$; and the above equation becomes

$$\frac{5x}{96} = \frac{2 \times 13000 \times .732 \times .366}{\frac{1}{2}x \sqrt{\left(1 - \frac{25x^2}{1800^2}\right)}},$$

which produces a cubic equation, whence the value of x may be determined.

It remains now to add a few particulars relative to the transverse strength of stones and metals, but our information on this head is limited; very few experiments having yet been attempted, except those of Mr. Banks on bars of cast-iron, and a few made by Dr. Robison on small pieces of marble.

Mr. Banks has, at various times, made many experiments on the real and comparative strength of oak, fir, and iron. He found that the worst or weakest piece of dry heart of oak, 1 inch square and 1 foot long, bore 660 lbs., though it was much bent, and 2 lbs. more broke it. The strongest piece he tried of the same dimensions broke with 974 lbs.; the worst piece of deal bore 460 lbs.; but broke with a little more.

With respect to cast-iron, he concludes that a bar of the weakest kind, an inch square and a foot long, would break with 2190 lbs.

The following are some of the experiments he mentions. See Banks on Power of Machines.

Experiment 1.—Two bars of cast-iron, 1 inch square and 3 feet long, were placed upon a horizontal bar, so as to meet in a cap at the top, from which was suspended a scale: these bars made each an angle of 45° with the base-plate, and, of consequence, formed an angle of 90° at the top: from this cap was suspended a weight of 7 tons, which was left for 16 hours, when the bars were a little bent, but very little.

Experiment 2.—Two bars, of the same length and thickness, were placed in a similar manner, making an angle of $22\frac{1}{2}^\circ$ with the base-plate: these bore four tons upon the scale; a little more weight broke one of them, which was observed to be a little crooked when first put up. In this case, the pressures would be as the sines of the angles of elevation,

viz. as 3826 to 7071; and as 3826 : 7071 :: 4 tons : 7.6 tons: that is, if the second bars broke with 4 tons, the first ought to have taken 7.6 tons to break them; and it is likely that would, if tried, have been the case.

Experiment 3.—Another bar was placed horizontally upon two supporters, exactly three feet distant, which bore 6 cwt. 3 qrs., or 675 lbs., but broke when a little more was added.

Experiment 4.—The same experiment repeated, with the same result.

Experiment 5.—The bearings were 2 feet 6 inches apart; the bar broke with 9 cwt. Three more experiments were tried at 3 feet; the average result was 6 cwt. 2 qrs. 7 lbs.

Experiments tried at Colebrooke-Dale, on curved Bars of Cast-Iron.

1. Rib 29 feet 3 inches span, a segment of a circle 3 feet high in the centre; it supported 99 cwt. 1 qr. 14 lbs.; it sunk in the middle $3\frac{7}{8}$ inches, and rose again three-fourths when the weights were removed: the same rib was afterwards tried without abutments, and broke with 55 cwt. 0 qr. 14 lbs.

2. Rib 29 feet 3 inches span, a segment of a circle 3 feet high in the centre; it supported 100 cwt. 1 qr. 14 lbs., and sunk $1\frac{1}{8}$ inches in the middle. The same rib was afterwards tried without abutments, and broke with 64 cwt. 1 qr. 14 lbs. The thickness of these ribs is not specified; but the experiments prove that each rib exerted little more than half the strength when the abutments were removed.

Mr. Banks made some experiments on the strength of cast-iron, at Messrs. Aydon and Elwell's foundry, Wakefield. The iron came from their furnace at Shelf, near Bradford, and was cast from the air-furnace; the bars 1 inch square, and the props exactly 3 feet distant; one yard in length weighed exactly 9 lbs., or one was about half an ounce less, the other a very little more; they all bent about an inch before they broke.

- | | | |
|--|---|----------|
| 1. The first bar broke with | - | 963 lbs. |
| 2. The second bar with | - | 958 |
| 3. The third bar with | - | 994 |
| 4. A bar made from the cupola | - | 864 |
| 5. A bar equally thick in the middle, but the ends formed into a parabolic form, and weighing 6 lbs. 3 oz. | - | 874 |

The same gentleman made many other experiments, and concludes, from the whole, that cast-iron is from $3\frac{1}{2}$ to $4\frac{1}{2}$ times stronger than oak of the same dimensions; and from 5 to $6\frac{1}{2}$ times stronger than deal.

We shall only observe here, that Mr. Banks's pieces of oak exceed very considerably the specimens that we have had an opportunity of trying, while his fir falls somewhat short of ours.

It was our intention, in conclusion, to have added a few examples illustrative of the several rules and principles laid down in the preceding pages; and also investigations relative to the form of beams possessing equal strength throughout, or beams of equal resistance; but as this article has already exceeded the usual limits, we can merely state the results, and must leave the investigation to the reader; or we may refer him to Gregory's *Treatise of Mechanics*, where all these subjects are investigated at length.

As the stress upon any beam submitted to a transverse strain is directly as the length, and the strength directly as the breadth into the square of the depth; it follows, if the sections are so proportioned to the lengths, that the breadth

into the square of the depth is always as the length or distance from the point where the weight acts ; that every part of the beam will be equally strong, in which case it is said to be a beam of equal resistance : hence, when a beam is fixed with one end in a wall,

1. If the breadth is the same throughout, the lengths must be as the square of the depths ; and consequently the vertical sides of the beam will be parabolas.

2. If the depth is the same throughout, the breadths must be as the lengths, and the upper and lower sides of the beam will be triangles.

3. If the several sections be circles, the cubes of their diameters (which is equivalent to the breadth into the square of the depth) must be as the lengths ; and the curve will be the cubic parabola.

4. The strongest beam that can be cut out of any cylindrical beam or tree, is that in which the breadth into the square of the depth is a maximum ; which will be the case when the squares of breadth and depth, and the square of the cylinder's diameter, are to each other as the numbers 1, 2, and 3.

As to our fourth head, relative to the wrenching or twisting of a body, very little that is satisfactory can be advanced ; according to Mr. Banks, a cast-iron bar an inch square, and fixed at one end, will break by the twist when 631 pounds are suspended by a wheel of two feet diameter, and made to act upon it ; though some have required more than 1000 lbs. in similar situations, to break them by the twist. The strength to resist the twisting strain is as the cube of like lateral dimensions.

Sugar

SUGAR, SACCHARUM, a very sweet, agreeable saline juice, expressed from a kind of canes, or reeds, growing in great plenty in the East and West Indies. (See SUGAR-CANE.) Pure sugar is perfectly transparent and colourless, when crystallized; but when granular, of a pure gloss of white, soluble in water and alcohol, without smell, and with a simply sweet taste, having no other flavour.

It is a question not yet decided among botanists, &c. whether the ancients were acquainted with this cane, and whether they knew how to express the juice from the same? What we can gather from the arguments advanced on either side is, that if they knew the cane, and juice, they did not know the art of condensing, hardening, and whitening it; and of consequence, they knew nothing of our sugar.

Some ancient authors, indeed, seem to mention sugar under the name of *Indian salt*; but they add, that it oozed out of the cane itself, and there hardened like a gum; and was even friable between the teeth, like our common salt; whereas sugar is expressed by a machine on purpose, and coagulated by the fire.

Theirs, Salmasius (Plinianæ Exercit. tom. i. p. 716. G.) tells us, was cooling and loosening; whereas ours, the same author asserts, is hot, and excites thirst. Hence some have imagined, that the ancient and modern sugar plants were different: but Matthioli on Dioscorides, c. 75. makes no doubt they were the same; and others are even of opinion, that ours has a laxative virtue, as well as that of the ancients, and that it purges pitta.

The generality of authors, however, agree, that the ancient sugar was much better than the modern; as consisting of only the finest and maturest parts, which made themselves a passage, and were condensed in the air. The interpreters of Avicenna and Serapion call sugar, *spodium*; the Persians, *tabaïr*; and the Indians, *mumbu*. Salmasius (Com. de Sacchar. apud Plin. Exercit. vol. ii. p. 257. A.D. 1689) assures us that the Arabs have used the art of making sugar, such as we now have it, above nine hun-

dred years.

Others produce the following verses of P. Terentius Varro Atacinus, to prove that it was known before Jesus Christ:

“Indica non magna nimis arbore crescit arundo:
Illius e lentis premitur radicibus humor,
Dulcia cui nequeant succo contendere mella.”

Dr. William Douglas, in his Summary, &c. of the first planting of our American settlements, printed at Boston in 1751, and reprinted at London in 1755, affirms, that sugar was not known among the ancient Greeks and Romans, who used only honey for sweetening. Paulus Ægineta, he says, a noted compiler of medical history, and one of the last Greek writers on that subject, about anno 1625, is the first who expressly mentions sugar: it was at first called *mel arundinaceum*, i. e. *reed or cane honey*. He adds that it came originally from China, by way of the East Indies and Arabia, into Europe, and was formerly used only in syrups, conserves, and such Arabian medicinal compositions.

Lucan, enumerating the eastern auxiliaries of Pompey, describes a people who used the cane-juice as a common drink.

“Qui bibunt tenerâ dulces ab arundine succos.”

Another question among the naturalists is, whether the sugar-canes be originally of the West Indies, or whether they have been translated rather from the East?

The learned of these last ages have been much divided on the point; but F. Labat, a Dominican missionary, in a dissertation published in 1722, asserts, that the sugar-cane is as natural to America as India; and that the Spaniards and Portuguese first learned from the Orientals the art of expressing its juice, boiling it, and reducing it into sugar.

Those who adopt this opinion assert, that the sugar-cane

was found growing spontaneously in many parts of the new hemisphere, when first explored by the Spanish invaders. In support of this opinion, Labat quotes, among other authorities, that of Thomas Gage, an Englishman, who went to New Spain in 1625, and who enumerates sugar-canes among the fruits and provisions with which the Charaibes of Guadaloupe supplied the crew of his ship. Labat further adds, that, besides the evidence of Francis Ximenes, who, in a treatise on American plants, printed at Mexico, asserts that the sugar-cane grows without cultivation, and to an extraordinary size, on the banks of the river Plata, we are assured by Jean de Lery, a Protestant minister, who was chaplain, in 1556, to the Dutch garrison in the fort of Coligny, on the river Janeiro, that he himself found sugar-canes in great abundance in many places on the banks of that river, and in situations never visited by the Portuguese. Father Hennepin, and other voyagers, bear testimony, in like manner, to the growth of the cane near the mouth of the Mississippi; and Jean de Laet to its spontaneous production in the island of St. Vincent. Hence it is concluded, that it is not for the plant itself, but for the secret of making sugar from it, that the West Indians are indebted to the Spaniards and Portuguese; and these to the nations of the East. Thus Labat reasons, and Lafitau is of opinion that his reasoning is incontrovertible; and it is also greatly confirmed by recent discoveries; the sugar-cane having been found in many of the islands of the Pacific ocean, by our late illustrious navigator captain Cook. In these accounts, says Mr. B. Edwards, there is no contradiction. The sugar-cane might have grown spontaneously in many parts of the new world; and Columbus, unapprized of the circumstance, might likewise have carried some of the plants to Hispaniola; and this most probably was the fact.

However this be, the industry with which the Spanish settlers applied to its cultivation, affords a wonderful contrast to the manners of the present inhabitants; since it appears, by the testimony of Oviedo, that no less than 30 ingenios, or sugar-mills, were established on that island so early as the year 1535.

Other writers, however, have maintained, that it was not known in America till the Europeans transplanted it thither. Its origin appears to have been from the inland continent of Asia, very probably as far east as China, where it still greatly abounds. From that continent it was first transplanted to Cyprus, and thence (according to various authors) into Sicily, where considerable quantities of it were produced about the year 1148, and whither, as some have asserted, it was brought from India by the Saracens. Lafitau conjectures, that the plant itself was unknown in Christendom, until the time of the Crusades. Its cultivation, and the method of expressing and purifying the juice, as practised by the inhabitants of Acra and Tripoli, are described by Albertus Aquensis, a monkish writer, who observes, that the Christian soldiers in the Holy Land frequently derived refreshment and support, in a scarcity of provisions, by sucking the canes. It flourished also in the Morea, and in the islands of Rhodes and Malta, and from thence was transported into Sicily, but the time is not precisely ascertained. Lafitau recites a donation of William, the second king of Sicily, to the monastery of St. Bennet, of a mill for grinding sugar-canes, with all its rights, members, and appurtenances. This happened in 1166. From Sicily it was transplanted by the Portuguese to Madeira about the year 1420, and from Sicily, or the southern coasts of Africa, or, as Herrera, the American historian, observes, from Granada, which derived it from Valencia, whither it might have been transplanted by the

Arabian Moors, it was brought to the Canaries; from the Canary isles to Brasil; where, indeed, some suppose sugar was originally and spontaneously produced. Others are of opinion, that the Portuguese, before they discovered, or at least planted in Brasil, being in possession of the coast of Angola in Africa, first transplanted the sugar-cane from Angola to Brasil. About the year 1506, sugar-canes were brought from Brasil and the Canaries, and planted in the island of Hispaniola, where many sugar-mills were gradually erected. It appears, however, by the testimony of Peter Martyr, in the third book of his first Decad, written during Columbus's second expedition, which began in 1493 and ended in 1495, that the sugar-cane was at that period sufficiently known in Hispaniola. The fact seems to have been, that Columbus himself carried it thither, among other articles and productions which he conveyed from Old Spain, and the Canary islands, where it grew, in his second voyage. In 1641, sugar-canes were transplanted from Brasil to Barbadoes, and thence to our other West India isles: as from Brasil they were also carried to the Spanish West India isles, and also the Spanish dominions in Mexico, Peru, and Chili; and lastly, to the French, Dutch, and Danish colonies.

The boiling and baking of sugars, says Dr. Heylin in his *Cosmography*, the first edition of which was printed in 1624, as it is now used, is not above two hundred years old; and the refining of it more new than that, first found out by a Venetian in the days of our forefathers, who got one hundred thousand crowns by the invention. Before which art of boiling and refining it, our ancestors made use of it rough as it came from the canes, but they most commonly used honey instead of it. The first account we have of sugar-refiners in England is in the year 1659. *Aunderdon's Hist. of Com.* vol. i. p. 82. 246. 331. 334. vol. ii. p. 72—105.

SUGAR-Cane, in *Botany*. See SACCHARUM.

The root of this plant is jointed like those of the other sorts of canes and reeds, from which arise four, five, or more shoots, according to the age or strength of the root: these grow from eight or ten to twenty feet high, according to the richness of the ground; but those of middling growth are the best.

The canes are also jointed, and the length as well as the size of the joints depend upon the weather and the soil; at each joint are placed leaves, the lower part of which embraces the stalk or cane to the next joint above their insertion, before they expand. The first joint, which comes out either at the third, fourth, or fifth month, according to the season and soil, always keeps in its first place near the earth; out of this comes the second, and out of the second a third, &c. each week producing its joint, or very nearly, and a corresponding leaf likewise drying and falling off nearly every week.

A cane of thirty-two joints, which is fit to be cut, has from five to twenty-eight of them which have lost their leaves; the next five or six still have them, in a withered state, and ready to fall off; and the remaining joints, surrounded with green leaves, form the head, which is cut off after the last leaf is withered. In a cane, whose length is from seven to nine feet, and which grows in a new, or a very moist and favourable soil, the number of useful joints is between forty and fifty, the first above the ground generally appearing at the end of three months, or, with frequent showers, a fortnight sooner; and many canes in such a soil are found rotten, or almost dried up, at the end of thirteen months: in a good soil, favourably exposed, well drained, and worked for a number of years, canes not shorter than four feet and a half have thirty-eight or forty joints, the first

joint appearing about the fourth or middle of the third month, and many canes that have been cut in such a soil at the end of fourteen or fifteen months being found rotted or dried: in a dry, but good soil, not manured, but well worked, and seconded by the season, the canes have been from three to four feet long, and have had from thirty to thirty-four joints; the first joint coming out at the end of four or four months and a half; and canes of this kind have been found standing at the end of fifteen months, but very dry, and sometimes a little changed: in a soil which is still drier, and more parched, canes which have been about two feet high have had from twenty-four to twenty-eight joints, the first of which appears at the end of the fifth month, and many of these canes have been dried at the end of fifteen months. From these and similar observations on the growth of canes in various kinds of soil, it has been inferred, that if there be any in which they can exist till the fifteenth or sixteenth month, they never grow to any kind of purpose in any after the thirteenth, or even after the twelfth. A deep soil and light land are most suitable to the sugar-cane; and the rainy season is the proper time for planting it: the sooner they are planted after the rains begin to fall, the more time they have to get strength before the dry weather sets in.

If the ground is proper for the sugar-canes, and they are planted at a good distance from each other, and the land is carefully managed by changing the crops to other species, or allowing a fallow to rest and recover itself, the same plantation, says Mr. Miller, may be continued above twenty years without replanting, and produce good crops the whole time: whereas in the common method, they are generally replanted in six or seven years, and in some of the poor land they are continued but two or three years. The canes are propagated by cuttings or joints of proper lengths, from fifteen to twenty inches, in proportion to the nearness of the joints; which are generally taken from the tops of the canes, just below the leaves: but Mr. Miller says, that if they were chosen from the lower part, where they are less succulent and better ripened, they would not produce canes so luxuriant, but their juice would be less crude, and contain a greater quantity of salts, which would be obtained by less boiling than that of those commonly planted. However, Mr. Cazaud, a late writer, and a planter of sugar-canes, observes, that the upper part, commonly called the head, is the best part that can be used for propagating them; and he recommends to put the plant in the ground as soon as it is cut. The distance which the canes are usually allowed in planting is from three to four feet, row from row; and the hills are about two feet asunder in the rows, in each of which hills they plant from four to seven or eight cuttings: instead of which number, productive often of blights, Mr. Miller is of opinion, that if one good cutting were planted in each hill, or two at most; and if both succeeded, the weakest were drawn out soon after they had taken, blights would be prevented, and the quantity of sugar would be full as great, and require little more than a fourth part of the fuel to boil it. In the proper season for planting, the ground should be marked out by a line, that the rows of canes may be straight and at equal distances; and the whole should be divided into pieces of sixty or seventy feet broad, leaving intervals between each of about twenty feet, for the convenience of passage, and for the admission of the sun and air between the canes.

The common method of planting the canes now practised, is to make a trench with the hoe, which is performed by the hand; into this a negro drops the number of cuttings intended to be planted, which are planted by other negroes,

and the earth drawn about the hills with the hoe, all which is performed by the hand: but if the right use of the plough was introduced, the work would be both better and cheaper performed. If, therefore, instead of a trench drawn by the hoe, a deep furrow is made with a plough, and the cuttings properly planted therein, the ground being deeper stirred, will be more favourable to the growth of the canes.

If the ground is afterward to be kept clear by the horse-hoe, the rows of canes should be five feet asunder, and the hills be two feet and a half distant; and but one cane left in each hill. After they have made some shoots, the sooner the horse-hoe is used, the more they will thrive, by keeping the weeds under, and well stirring the land.

When the canes are from seven to ten feet high, and of proportionable size, the skin smooth, dry, and brittle; if they are heavy, their pith grey or inclinable to brown, the juice sweet and glutinous; they are esteemed in perfection.

Mr. Cazaud observes, that the withering and fall of a leaf is the only and a sufficient criterion of the maturity of the joint to which it adhered; and that the eight last joints of two canes, which are cut the same day, have exactly the same age and the same degree of ripeness, notwithstanding one of the canes may be fifteen, and the other only ten months old: to which purpose he adds, that each joint of the cane of a supposed growth of ten months, contained the same quantity of sugar as that of a cane of the supposed growth of fifteen.

The time for cutting them is usually after twelve or fifteen months growth, but this varies according to the soil and the season. Those which are cut toward the end of the dry season, before the rains begin to fall, produce better sugar than those cut in the rainy seasons, when they are more replete with watery juice, and require a greater expence of fuel to boil it.

In those plantations where the number of negroes is small, sugar is made in almost all seasons indifferently, and consequently the canes are planted when the planter is best prepared for his work, rather than at the most advantageous time. The system of cultivation among planters, who are better supplied in respect of labourers, consists in planting a fourth or a fifth of their land in October, November, and December; in digging very deep trenches, for the greater nourishment of the root; in planting at great distances, for the benefit of a freer circulation of the air; and in cutting the canes in the four finest months, *viz.* February, March, April, and May, because the sugar is then the finest, the canes are cut with the least trouble, and supply (as is supposed) greater quantities of it. Those who adopt this method, cut about three-fourths of their plantations, the remaining being made up of young canes, to be cut the following year, and for new plants.

Mr. Cazaud, who has made many judicious observations and experiments on the cultivation of the sugar-cane, has adopted a new method. He employs the whole of the first six months of the year in the business of the crop, and in May and June plants the canes which have been cut in January. This of course induces a necessity of cutting the ratoons (or the canes proceeding from the old stumps) at the end of the eleventh instead of the end of the twelfth month, and the planted canes, which should stand fifteen months, at the end of the year; so that the whole plantation is cut every year; and he only plants a sixth part of his land every year. He has largely illustrated the reasons and advantages of this method; the fundamental principle of which is the necessity of planting the canes in the only

season fitted to accelerate and preserve them: as in the Windward islands, the weather is commonly dry from the 15th of February to the 15th of May, and the rains are moderate till August, and copious the two or three following months, and afterwards decrease till February: and, therefore, the progression of the rain keeps pace, as it were, with that of the canes, when they are planted in May. With regard to the maturity of the cane, as far as it is of consequence to the sugar, this, he says, does not depend on the age, but on the season. In February, March, and April, all the canes, whatever be their age, are as ripe as the nature of the soil ever allows them to be; and accordingly he never fails to make the greatest part of his sugar at this season. He observes, that the dryness of the weather, (and not the age of the canes,) which increases from January to April, is the cause, that in January four hundred gallons of juice commonly yield forty-eight gallons of sugar and melasses one with another; in February, from fifty-six to sixty-four; in March, from sixty-four to seventy-two; in April, sometimes eighty; after which period the sugar ferments, and even burns when the refiner is not very expert at his business. The greatest relative maturity of his canes he infers to be, when the juice of them was made up of four parts water, and one part of sugar and melasses: and in canes perfectly ripe, the quantity of sugar, he says, is equal to that of the melasses. After a trial of this plan for five years, he is convinced that there is a difference of above one-sixth in its favour. Miller's Gard. Dict. Phil. Transf. vol. lxxix. part 1. art. xix. p. 207, &c.

The best soil, according to Mr. Edwards, which he has seen or heard of, for the production of sugar of the finest quality, and in the largest proportion, is the ashy loam of St. Christopher's. Next to that is the soil, which in Jamaica is called the brick-mould, containing a due mixture of clay and sand. Plant-canes in this soil (which are those of the first growth) have been known, in very fine seasons, to yield two tons and a half of sugar *per* acre. After this may be reckoned the black mould of several varieties. The best is the deep black earth of Barbadoes, Antigua, and some other of the Windward islands; but there is a species of this mould in Jamaica, that is little if at all inferior to it, which abounds with lime-stone and flint, on a substratum of soapy marl. We shall not enumerate the varieties of soil proper for this kind of culture; but content ourselves with mentioning a peculiar sort of land on the north side of Jamaica, chiefly in the parish of Trelawney, as few soils produce finer sugars, or such as answer so well in the pan, or which yield a greater return of refined sugar. This land is of a red colour, varying by different shades; but every where remarkable, when first turned up, for a glossy or shining surface, and, if wetted, for staining the fingers like paint. This soil seems to consist of a native earth, or pure loam, with a mixture of clay and sand. It is easily wrought, and at the same time so tenacious, that a pond dug in this soil in a proper situation, with no other bottom than its own natural texture, holds water like the stiffest clay. The system of husbandry in sugar plantations, which abound with this, chiefly depends on what are called ratoon-canes.

In most parts of the West Indies, it is usual to hole and plant a certain proportion of the cane-land (commonly one-third), in annual succession. The common yielding of this land, on an average, is seven hogheads of 16 cwt. to ten acres, which are cut annually. In the cultivation of other lands, especially in Jamaica, the plough has been introduced of late years, and in some few cases to great advantage; but the use of the plough is not adapted to every soil or situa-

tion. The only advantageous system of ploughing in the West Indies is to confine it to the simple operation of *holing*, which is much more easily and expeditiously performed by the plough than by the hoe, and which affords, in the case of stiff and dry soils, great relief to the negroes. The method of *holing* has been already described. The proper season, generally speaking, for planting, is in the interval between August and the beginning of November. By having the advantage of the autumnal season, the young canes become sufficiently luxuriant to shade the ground before the dry weather sets in: thus the roots are kept cool, and the earth moist. By these means, they are ripe for the mill in the beginning of the second year, so as to enable the overseer or manager to finish his crop by the latter end of May. It has been justly remarked, that there is not a greater error in the system of planting, than to make sugar, or plant canes, in improper seasons of the year; for by mismanagement of this kind, every succeeding crop is put out of regular order. However, neither prudence in the management, nor favourable soils, nor seasonable weather, will exempt the planter at all times from misfortune in the culture of his sugar-canes. They are subject to a disease called the "blight," which consists of many myriads of little insects of the aphid genus, said to be invisible to the unassisted eye, whose proper food is the juice of the cane; in pursuit of which they wound the tender blades, and destroy the vessels. The circulation is thus impeded, and the growth of the plant is checked, until it withers or dies in proportion to the degree of the ravage. In some of the Windward islands, the cane in dry weather is liable to be destroyed by a species of grub, called the "borer." In Tobago they have another destructive insect, called the "jumper-fly." It is said that the "blight" never attacks those plantations, where colonies have been introduced of the little animal, called the carnivorous ant; the "formica omnivora" of Linnæus, and the "Raffles" ant of Jamaica.

The manure generally used in sugar-planting is a compost formed of the coal and vegetable ashes, drawn from the fires of the boiling and still-houses; feculencies discharged from the still-house, mixed with rubbish of buildings, white lime, &c.; refuse, or field-trash, i. e. the decayed leaves and stems of the canes, so called in contradistinction to cane-trash used for fuel; dung, obtained from the horse and mule stables, and from cattle-pens; and good mould, collected from gullies, or other waste places, and thrown into the cattle-pens.

When the rattoons or canes are ripe, as they ordinarily are in twelve or fifteen months, or, as Mr. Cazaud apprehends, in eleven or twelve months, they are cut, and carried in bundles to the mills. The mills consist of three wooden rollers, covered with steel or iron plates; and have their motion either from the water, the wind, cattle, or even the hands of slaves. These rollers or cylinders are from 30 to 40 inches in length, and from 20 to 25 inches in diameter; and the middle one, to which the moving power is applied, turns the other two by means of cogs. Between these rollers the canes, being previously cut, are twice compressed; for having passed the first and second rollers, they are turned round the middle one by a circular piece of frame-work, or screw, called in Jamaica the "dumb-returner," and forced back through the second and third; an operation which squeezes them completely dry, and sometimes even reduces them to powder. (For a farther account of sugar-mills, see the sequel of this article.) The juice from the mill ordinarily contains eight parts of pure water, one part of sugar, and one part made of gross oil and mucilaginous gum, with a portion of essential oil. Some juice, however, has been so rich

as to make a hoghead (16 cwt.) of sugar from 1300 gallons; and some so watery as to require more than double that quantity. A pound of sugar from a gallon of raw liquor is reckoned, in Jamaica, very good yielding.

SUGAR, Preparation of. The juice or liquor runs from the receiver to the boiling-house, along a wooden gutter lined with lead. In the boiling-house it is received (according to the modern improved system, which almost universally prevails in Jamaica) into one of the copper pans or cauldrons, called clarifiers. Of these, there are commonly three; and their dimensions are generally determined by the power of supplying them with liquor. There are water-mills that will grind, with great ease, canes sufficient for thirty hogheads of sugar in a week. On plantations thus happily provided, the means of quick boiling are indispensably requisite, or the cane-liquor will unavoidably become tainted before it can be exposed to the fire. The purest cane-juice will not remain twenty minutes in the receiver without fermenting. As cane-juice is so very liable to fermentation, it is necessary also that the canes should be ground as soon as possible after they are cut, and great care taken to keep and throw aside those which are tainted, which may afterwards be ground for the still-house. Clarifiers, therefore, are sometimes seen of one thousand gallons each. On estates that make on a medium, during crop-time, from fifteen to twenty hogheads of sugar a week, three clarifiers of three or four hundred gallons each are sufficient. With pans of this size, the liquor, when clarified, may be drawn off at once; and there is leisure to cleanse the vessels every time they are used. Each clarifier is provided either with a siphon or cock for drawing off the liquor. It has a flat bottom, and is hung to a separate fire, each chimney having an iron slider, which being shut, the fire goes out for want of air. These circumstances are indispensable, and the advantages of them will presently be shewn. The clarifiers are commonly placed in the middle or at one end of the boiling-house. If at one end, the boiler called the "teache" is placed at the other, and several boilers (generally three) are ranged between them. The teache is ordinarily from 70 to 100 gallons, and the boilers between the clarifiers and teache diminish in size from the first to the last. Where the clarifiers are in the middle, there is usually a set of three boilers on each side, which constitute in effect a double boiling-house. On very large estates, this arrangement is found useful and necessary. The objection to so great a number is the expence of fuel; to obviate which, in some degree, the three boilers on each side of the clarifiers are commonly hung to one fire.

The stream then from the receiver having filled the clarifier with fresh liquor, and the fire being lighted, the "temper," which is commonly Bristol white-lime in powder, is stirred into it. One great intention of this is to neutralize the superabundant acid, to get properly rid of which, is the great difficulty in sugar-making. This is generally effected by the alkali or lime; part of which, at the same time, becomes the basis of the sugar. The quantity necessary for this purpose must, of course, vary with the quality both of the lime and of the cane-liquor. Some planters allow a pint of Bristol lime to every hundred gallons of liquor; but this proportion is, Mr. Edwards believes, generally found too large. The lime is perceptible in the sugar, both to the smell and taste, and precipitates in the copper pans a black insoluble calx, which scorches the bottom of the vessels, and is not detached without difficulty. Mr. Edwards is of opinion, therefore, that little more than half the quantity mentioned above is a better medium proportion; and, in order that less of it may be

precipitated to the bottom, an inconveniency attending the use of dry lime, Mr. Bouffie's method of dissolving it in boiling water, previous to mixing it with the cane-juice, appears to him to be highly judicious. In some parts of Jamaica, where the cane-liquor was exceedingly rich, Mr. Bouffie made very good sugar without a particle of temper. Too much temper is perceptible in the sugar, both to the smell and taste: it might be added, *and also to the sight*. It tinges the liquor first yellow, and, if in excess, turns it to a dark red. Too much temper likewise prevents the metalles from separating from the sugar, when it is potted or put into the hoghead.

As the fire increases in force, and the liquor grows hot, a scum is thrown up, which is formed of the mucilage or gummy matter of the cane, with some of the oil, and such impurities as the mucilage is capable of entangling. The heat is now suffered gradually to increase, until it rises to within a few degrees of the heat of boiling water. The liquor must by no means be suffered to boil: it is known to be sufficiently heated, when the scum begins to rise into blisters, which break into white froth, and appear in general in about forty minutes. The damper is then applied, and the fire extinguished; after which, the liquor is suffered to remain a full hour, if circumstances will permit, undisturbed. During this interval, great part of the feculencies and impurities will attract each other, and rise in the scum. The liquor is now carefully drawn off, either by a siphon, which draws up a pure defecated stream through the scum, or by means of a cock at the bottom. In either case, the scum sinks down unbroken as the liquor flows, its tenacity preventing any admixture. The liquor is received into a gutter or channel, which conveys it to the evaporating boiler, commonly called the "grand copper;" and, if originally produced from good and untainted canes, will now appear almost, if not perfectly, transparent. The merit of introducing into Jamaica the clarifiers at present in use with siphons and dampers, was claimed by Mr. Samuel Sainthill; and an exclusive patent, to secure his claim, was granted to him in 1778, by an act of the assembly.

The advantage of clarifying the liquor in this manner, instead of forcing an immediate ebullition, as practised formerly, is visible to the most inattentive observer. The labour which it saves in scumming is wonderful. Neither can scumming properly cleanse the subject; for when the liquor boils violently, the whole body of it circulates with such rapidity, as to carry down again the very impurities that had come up to the surface, and which with a less violent heat would have staid there.

In the grand or evaporating copper, which should be large enough to receive the net contents of one of the clarifiers, the liquor is suffered to boil; and as the scum rises, it is continually taken off by large scummers, until the liquor grows finer and somewhat thicker. This labour is continued until, from the scumming and evaporation, the subject is sufficiently reduced in quantity to be contained in the next or second copper, into which it is then laded. The liquor is now nearly of the colour of Madeira wine. In the second copper the boiling and scumming are continued; and if the subject is not so clean as is expected, lime-water is thrown into it. This addition is intended not merely to give more temper, but also to dilute the liquor, which sometimes thickens too fast to permit the feculencies to run together, and rise in the scum. Liquor is said to have a good appearance in the second copper, when the froth in boiling arises in large bubbles, and is but little discoloured. When, from such scumming and evaporation, the liquor is again sufficiently reduced to be contained in the third copper, it

is laded into it, and so on to the last copper, which is called the "teache," probably from the practice of trying by the touch. This arrangement supposes four boilers or coppers, exclusive of the three clarifiers.

In the teache the subject is still farther evaporated, till it is judged sufficiently boiled to be removed from the fire. This operation is usually called "striking;" *i. e.* lading the liquor, now exceedingly thick, into the cooler.

The cooler, of which there are commonly six, is a shallow wooden vessel, about eleven inches deep, seven feet in length, and from five to six feet wide. A cooler of this size holds a hoghead of sugar. Here the sugar grains; *i. e.* as it cools, it runs into a coarse irregular mass of imperfectly formed crystals, separating itself from the melasses. From the cooler it is carried to the curing-house, where the melasses drain from it. It may be proper in this place to observe, that, in order to obtain a large-grained sugar, it must be suffered to cool slowly and gradually. If the coolers are too shallow, the grain is injured in a surprising manner. Any person may be convinced of this, by pouring some of the hot syrup, when fit for striking, into a pewter plate: he will immediately find it will have a very small grain.

But, before we follow it into the curing-house, it may be proper to notice the rule for judging when the subject is sufficiently evaporated for "striking," or becomes fit for being laded from the teache to the cooler. Many of the negro boilers guess solely by the eye, (which by long habit they do with great accuracy,) judging by the appearance of the grain on the back of the ladle; but the practice most in use is to judge by what is called "the touch;" *i. e.* taking up with the thumb a small portion of the hot liquor from the ladle; and, as the heat diminishes, drawing with the forefinger the liquid into a thread. This thread will suddenly break, and shrink from the thumb to the suspended finger, in different lengths, according as the liquor is more or less boiled. The proper boiling height for strong muscovado sugar is generally determined by a thread of a quarter of an inch long. It is evident, that certainty in this experiment can be attained only by long habit; and that no verbal precepts will furnish any degree of skill in a matter depending wholly on constant practice.

A method more certain and scientific was recommended some years ago, by John Proculus Baker, *esq.*, barrister at law, in the island of Jamaica, in a treatise published by him in 1775, entitled "An Essay on the Art of making Muscovado Sugar." It is as follows: "Provide a small thin pane of clear crown glass, set in a frame, which I would call a 'tryer;' on this drop two or three drops of the subject, one on the other, and carry your tryer out of the boiling-house into the air. Observe your subject, and more particularly whether it grains freely, and whether a small edge of melasses separates at the bottom. I am well satisfied that a little experience will enable you to judge what appearance the whole skip will put on, when cold, by this specimen, which is also cold. This method is used by chemists, to try evaporated solutions of all other salts; it may seem, therefore, somewhat strange, it has not been long adopted in the boiling-house."

The present improved system of clarifying the cane-liquor, by means of vessels hung to separate fires, and provided with dampers to prevent ebullition, was first suggested, says Mr. Edwards, to Mr. Santhill, (who three years afterwards claimed the merit of the invention,) by the treatise in question.

The curing-house is a large airy building, provided with a cavernous melasses cistern, the sides of which are sloped and lined with terras, or boards. Over this cistern there is

a frame of maffy joist-work, without boarding. On the joists of this frame, empty hogheads, without headings are ranged. In the bottoms of these hogheads eight or ten holes are bored, through each of which the stalk of a plantain leaf is thrust, six or eight inches below the joists, and long enough to stand upright above the top of the hoghead. Into these hogheads the mass from the cooler is put, which is called "potting;" and the melasses drain through the spongy stalk, and drop into the cistern, from whence it is occasionally taken for distillation. The sugar, in about three weeks, grows tolerably dry and fair. It is then said to be cured, and the process is finished. The curing-house should be close and warm, as warmth contributes to free the sugar from the melasses.

Sugar, thus obtained, is called "muscovado," and is the raw material from which the British sugar-bakers chiefly make their loaf, or refined lump. There is another sort, which was formerly much approved in Great Britain for domestic purposes, and was generally known by the name of Lisbon sugar. It is fair, but of a soft texture, and in the West Indies is called "clayed sugar." The process is conducted as follows: A quantity of sugar from the cooler is put into conical pots or pans, called by the French "formes," with the points downwards, having a hole about half an inch in diameter at the bottom, for the melasses to drain through, but which at first is closed with a plug. When the sugar in these pots is cool, and become a fixed body, which is discoverable by the middle of the top falling in, (generally about twelve hours from the first potting of the hot sugar,) the plug is taken out, and the pot placed over a large jar, intended to receive the syrup or melasses that drain from it. In this state it is left as long as the melasses continue to drop, which it will do from twelve to twenty-four hours, when a stratum of clay is spread on the sugar, and moistened with water, which oozing imperceptibly through the pores of the clay, unites intimately with, and dilutes the melasses; consequently more of it comes away than from sugar cured in the hoghead, and the sugar, of course, becomes so much the whiter and purer. The pots remain for twenty days in this situation, after which the sugar is taken out, dried in the sun for some hours, and then taken to a large store-room, where it is kept in a pretty strong heat for three weeks. The process, according to Sloane, was first discovered in Brazil, by accident. "A hen," says he, "having her feet dirty, going over a pot of sugar, it was found under her tread to be whiter than elsewhere." The reason assigned why this process is not universally adopted in the British sugar islands is this, that the water, which dilutes and carries away the melasses, dissolves and carries with it so much of the sugar, that the difference in quality does not pay for the difference in quantity. The French planters probably think otherwise, upwards of four hundred of the plantations of St. Domingo having the necessary apparatus for claying, and actually carrying on the system. The loss in weight by claying is about one-third: thus, a pot of 60 pounds is reduced to 40 pounds; but if the melasses which are drawn off in this practice be reboiled, they will give nearly 40 per cent. of sugar; so that the real loss is little more than one-sixth: but the distillery, in that case, will suffer for want of the melasses; and, on the whole, Mr. Edwards believes that the usage of the English planters in shipping muscovado sugar, and distilling the melasses, is more generally profitable than the system of claying.

The Cochinchinese prepare a very excellent moist sugar, remarkably cheap, by a very simple process, similar to that of claying. The grained sugar, after the grofs syrup has drained from it, and it has become considerably solid, is

placed in layers about an inch thick, under layers of the same dimensions of the herbaceous trunk of the plantain tree; the watery juices, exuding from which, act like claying, and leave the sugar very white and porous, like a honey-comb. This is pure enough to dissolve in water, without any sediment.

F. Labat mentions several different kinds of sugars, prepared in the Caribbees, viz. *Crude sugar*, or *muscovado*; *strained*, or *brown sugar*; *earthed*, or *white sugar* in powder; *refined sugar*, either in powder or loaves; *royal sugar*; *candied sugar*; *sugar of fine syrup*; *sugar of coarse syrup*; *sugar of the scum*.

SUGAR, Crude, or Muscovado, is that first drawn from the juice of the cane; of which all the rest are composed. The method of making it is that already described as for sugar in the general.

SUGAR, Strained, or Brown, though somewhat whiter and harder, does not differ much from the crude sugar; though it is held a medium between this last and the earthed sugar; which is the white powder sugar.

The preparation of this is the same as that of the muscovado, with this difference, that, to whiten it, they strain the liquor through blankets, as it comes out of the first copper. The invention of strained sugar is owing to the English, who are more careful than their neighbours in the preparation of it; for they not only strain it, but, when boiled, put it into square wooden forms, or moulds, of a pyramidal figure; and when it has purified itself well, they cut it in pieces, dry it in stoves, and barrel it up. See *Refining of SUGAR, infra*.

SUGAR, Earthed, is that which is whitened by means of earth laid on the top of the forms it is put in to purge itself. See *Refining of SUGAR*.

SUGAR of the Scum. This is all made of the scum of the two last coppers; those of the former being reserved for the making of rum.

The scum destined to make sugar is kept in a vessel for that purpose, and is boiled every morning in a copper set apart for that use. With the scum, is put into the copper a fourth part of water, to retard the boiling, and give time for its purging; when it begins to boil, the usual ley is put in, and it is carefully scummed: when almost enough boiled, lime and alum-water are thrown in; and when it is ready to be taken out, they sprinkle it with a little powdered alum.

SUGAR of Syrup, or Treacle. There are three kinds of syrups that run from sugar. The first, from the barrels of raw sugar, which is the coarsest of all; the second, from the forms, or moulds, after they are perforated, and before they receive their earth; the third, that coming from the forms after they have had their earth; which last is the best.

The coarse syrups should only be used for rum, but sugar being grown dear, endeavours have been used to make some of them, and that with tolerable success. They are first clarified with lime-water; and, when boiled, are put up in barrels, with a sugar-cane in the middle, to make them purify themselves. After twenty days, a quantity of coarse earth is thrown in, to make them cast the remainder of their syrup, and fit them to be returned into a crude sugar. The Dutch and German refiners first taught the islanders how to turn their treacle into sugar.

The second syrup is wrought somewhat differently: after the copper it is to be boiled in is half full, eight or ten quarts of lime-water are cast in; it is then boiled with a brisk fire, and carefully scummed; some add a ley, and others none. F. Labat takes the former method to be the better,

though it requires more trouble and attention. This sugar may be earthed alone, or at least with the heads of loaves, the dried tops, and such other kinds of sugars as may not be mixed with the true earthed sugar, nor yet with the crude sugar.

For the third syrup, after boiling and scumming it as the former, they put it instantly into coolers, the bottoms of which are covered half an inch thick with white sugar, very dry and well pounded; and the whole is well stirred to incorporate the two together. This done, they strew the surface over with the same pounded sugar, to the thickness of one-fifth of an inch, this assisting the sugar in forming its grain. When settled, and the crust gathered at the top, a hole is made in the crust five or six inches in diameter.

By this aperture they fill the cooler with a new syrup, poured gently in, which insensibly raises up the former crust. When all the syrups are boiled, and the cooler is full, they break all the crusts; and, after mixing them well, put them up in forms or moulds.

The rest is performed in the same manner as for the earthed sugar, from which it only differs in that it falls short of its gloss and brightness; being, in reality, sometimes whiter and finer, though of a flatter and duller white. For the use and management of the syrup of sugar, see *Refining of SUGAR*.

SUGAR, Refined. Crude sugar, strained sugar, and the heads or tops of loaves that have not whitened well, are the basis, or ground, of this sugar. See *Refining of SUGAR*.

SUGAR, Royal. The basis of this sort ought to be the purest refined sugar to be found. This they melt with a weak lime-water; and, sometimes, to make it the whiter, and prevent the lime from reddening it, they use alum-water. This they clarify three times, and pass as often through a close cloth, using the very best earth. When prepared with these precautions it is whiter than snow, and so transparent, that we see a finger touching it, even through the thickest part of the loaf.

The curious in the whole art of sugar-making, or the reducing vegetable juices to what we call sugar, by expression, decoction, clarification, graining, claying, and crystallization, will find farther accounts and directions, in the several processes of this art, in Piso's Hist. Ind.; in Angelus Sala's Saccharologia; in Dr. Stare's Treatise on Sugars; in Sir Hans Sloane's History of Jamaica; Baker's Essay, above cited; and Edwards's History of the West Indies, vol. ii. There are also several valuable papers on these subjects in the Philosophical Transactions.

SUGAR, Refining of, is the art of purifying sugar, and of giving it a superior degree of whiteness and solidity. The excellence of muscovado sugars, or such as have not been refined by the planter, but are sent home in the most crude state, consists in their whiteness, dryness or freeness, cleanliness and sharpness, or strength. The judicious refiner decides upon these several qualities by the eye, the touch, and the taste.

The first operation in the process of refining is that of *clearing the pans*; previously to which they are charged, by throwing about six quarts of fresh bullock's blood (called *spice*) into each pan, and filling it with lime-water to about half the height from the bottom to the part in which the brace is fixed; and when these are well stirred together, the pan is filled to the brim with raw sugar. This mass, with a moderate fire, will in about two hours be brought to the verge of boiling heat; but it should not be allowed actually to boil; and in this time the earthy particles of the sugar, and other adventitious impurities, will be separated from it by the effect of the heat, and the cleansing quality

of the spice, and thrown up to the surface. About two quarts of spice are added to each pan, within the first hour after the fires are lighted. The scum thus produced, which is usually from four to ten inches thick, is fit to be taken off, when the surface appears black and dry, and not greasy; and it is gently removed with a broad skimmer into a portable tub, and conveyed into the scum-cistern. Having done this, the panman stirs together a ladleful of spice (*c. gr.* about a quart), and a quantity of lime-water (*c. gr.* one or two gallons, as the case may require); and pours this mixture into each pan. When the sugar is again brought to a scalding heat, it throws up a second scum, not so foul as the first, which is removed as before. He then adds a fresh quantity of spice, but less than the former, and repeats this operation, till the sugar casts up a clean milky froth, which indicates that the impurity is wholly extracted. The liquor is also sometimes examined with a bright silver or metal spoon, that any remaining foulness may be discovered. In the making of double loaves, powder loaves, or very fine single loaves, it is usual to heighten the natural colour of the sugar by the addition of a little blue. For this purpose, when the pans are almost clear, the quantity of about six pennyweights troy of the finest indigo, finely powdered and filtered through a piece of woollen or blanketing in a basin of fresh water, and well stirred together in a basin, is thrown into each pan. The sugar being once raised in the pan after this infusion, the grosser particles of the colour are taken off in the last scum, and the remainder is incorporated with the sugar in the pan.

The panman having brought the sugar to the cleanest state, prepares to *skip it off*, or to shift it from one vessel to another: this is done by means of a wooden gutter laid along the pans, and opening into the clarifying cistern. Over this cistern, upon large iron bars, is fixed an oblong basket, about sixteen inches deep, in which a large thick blanket is fastened; and through this blanket and basket the sugar liquid passes out of the gutter; and to the mass a quantity of syrup is usually added. Having measured the quantity of liquid in the cistern with a rod graduated by inches, the panman pumps back into the pans either the sixth or ninth part of the whole, as he is directed by the supervisor or boiler; and the pans are all supplied together by means of a trough. When this is done, the fire is stirred up to a considerable degree of fierceness; and then commences a new operation, *viz. evaporation*. In this part of the process (the day's work being divided into three fillings), the panman pumps into the pan one-ninth part of the quantity in the cistern, which in a few seconds begins to boil, and must be continued in a boiling state, but not with too intense a fire; and to prevent the sugar from boiling up to the surface of the pan, or from boiling over, he casts a small quantity (*viz.* a piece as large as a nutmeg or walnut, as the case may require) of butter or grease into the boiling liquor. Here it is to be observed, that sugar should boil low in the pan, and yet not too flat, like water; for by rising hollow from the bottom, the necessary evaporation is retarded, and the sugar is exposed to the action of the fire for a longer time than it ought to be. In a space of time from twelve to thirty minutes, the evaporation will have produced its effect, and the sugar acquire the requisite degree of viscoseness. The state will be indicated by various circumstances; as by the bubbles dragging heavily over the surface of the boiling mass, and by the clammy liquid falling in ropes from the proof-stick; but principally by that test which is called the *proof*. For this purpose the boiler draws the stick out of the boiling liquid with his right hand, and placing his left thumb upon

the sugar, draws it across the stick, carrying away upon the end of his thumb as much of the sugar as will hang upon it: he then, by means of a candle placed in a black box, called the proof-box, and by repeated trials (drawing the sugar to a thread between his thumb and fore-finger) determines when the evaporation is complete; and when this is decided, the fire is smothered, and nearly quenched. The hot sugar-liquor is then removed by means of basons out of the pans into coolers, two or three gallons being left in each pan to prevent the bottom from being scorched; and the pans are again supplied with a quantity of liquor for the next evaporation. The liquor in the coolers is gently stirred to prevent a crust from forming on its surface. When the second quantity is brought to proof, and skipped off into the coolers, the pans are supplied with a similar quantity; and while this is boiling, that part of the process of refining, called *granulation*, is pursued. For this purpose the sugar is disturbed in the coolers by an instrument called an *oar*, and resembling the oar of a boat: the violent motion thus continued for several minutes, serves to destroy the viscoseness of the sugar, and to complete the granulation. Upon this operation much of the beauty and success of the manufacture depend; for if the sugars are not stirred enough, the grain of the refined sugar will be large and loose, and its colour not sufficiently white; but if it be stirred too much, the grains will be broken, the sugar will be disunited in its parts, and though close and smooth, without lustre; and it will lose considerably of its due weight. When the third skipping is boiled, and the coolers sufficiently stirred, the contents of the pans are removed to the coolers, as before; and thus the first stage of boiling for the day is completed. The course of the other two fillings is precisely the same.

The next operation in refining is conducted in that part of the ground-floor of a sugar-house, which is denominated the *fill-house*, because all the upper floors of the house are to be filled from this; and this operation consists in *filling* the moulds with the three skippings contained in the coolers. The moulds, in the form of inverted cones, previously prepared by soaking and washing them, and stopping their apertures with wet linen rags, are placed side by side, and in rows two or three deep: their number is to suffice for the quantity of liquor in the coolers, which is estimated by the number of basons which were skipped off from the pans; and they are propped up by other moulds (commonly such as are broken) placed with the broad end downwards, in front of the outward rank, by way of abutment: these are called *stayers*. The sugar, being previously stirred in the coolers, in order thoroughly to mix each skipping, is ladled out of the coolers in succession, and not all at once, (unless the fillings are small, in loaves, and always in lumps,) into basons conveniently situated; and these are carried into the fill-house, where as much of the sugar is poured into each mould as will fill about one-third of its capacity; the same quantity is again poured into each; and at the third time they are filled to the brim.

The moulds being filled, the next operation, which is that of stirring the sugar in them, is called *hauling*, and is designed to prevent an adhesion to the mould, and to lay the grain of the mass even and regular through all its parts. In this business each man takes a tool, made of wainscot, and called a knife, and in size proportioned to that of the mould to be stirred; with this tool, keeping his hand over the centre of the mould, he scrapes the sugar from its sides by successive strokes downwards, carried all round; and when two revolutions are performed, the sugar is allowed to rest some minutes, until it has acquired some firmness. The moulds,

being stirred round three or four times, according to the direction of the boiler, are no more disturbed till they are pulled up.

The process already described relates to sugar *once refined*, called single loaves: double loaves are usually cleared with the whites of eggs instead of spice, (two hundred of which are necessary to each pan,) and with fresh water instead of lime-water. With respect to the proof, one rule only can be laid down; *viz.* the sugar must be boiled higher as the moulds which contain it are increased in size.

The order of refining is uniformly this: to begin the first day with the finest sugar intended to be wrought, and to proceed daily with sugar of a lower quality, and of course to begin with small loaf-moulds, and to use larger moulds progressively; so that the brownish sugar will be put into large lump-moulds; for this sugar works best in large masses, and it is likewise more in demand in England than the finer kind. The use of this distribution of a refining is to enable the boiler to make a more advantageous disposition of his syrups and scums. The order of the first twelve days is usually as follows: first day, double loaves; second and third days, powder loaves; fourth, fifth, and sixth, single loaves; seventh, Prussian lumps; eighth, Canary, or pattern lumps; ninth, tenth, eleventh, and twelfth days, large lumps. To these twelve days are added four or five more, in a part of the process called *bastard-boiling*; and these sixteen or seventeen days constitute a complete series, denominated a complement, or refining.

From this digression let us now return to the fill-house; where the second and third fillings having been boiled off, and passed from the coolers into the moulds, in the manner already described, the panman proceeds to make over the scum which was taken off the pans in the morning, in order to extract the remaining sugar from it; the method of doing this will be hereafter explained. When it is finished, the pans are loaded for the work of the following day. In the evening, when the new-made goods are cool, and fit for removal without damage, they are pulled up into that floor of the house which is best suited for receiving them, and where a proper number of well-sorted pots are placed in ranks for this purpose. The up-stairs man plucks out from the point of every one the stopper or rag; and pricks them in the point with an awl, the size of which is proportioned to the mould; and they are then set upon the pots.

The contents of the moulds, cleared by the preceding operations of their earthy particles and water, consist of the vegetable salt, and an oily matter, now called *syrup*, but which, after the final extraction of the salts, will be called *melasses*. For the separation of these there is required a series of operations, which may be distinguished by the name of *filtering*, or *draining*. In twenty-four hours after the loaves have been placed upon the pots, the quantity of syrup which will have exuded from the aperture of each, will fill more than half of the pot on which it stands. When the state of the loaves has been examined, by drawing one or two loaves of each filling out of their moulds, if the syrups are not in a digesting state, they are left unclayed for two or three days longer, and the warmth of the room in which they stand is somewhat increased; but if they manifest a proper appearance, they are prepared for receiving the first clay, which is laid on either the next or the third day. The green new-made loaves are judged to bear a healthy and promising appearance, when the syrups have quit the broad part of the loaf, and are evenly drawn together; and when the whole surface has a compact and smooth appearance, they are fit to receive clay. When the

syrup hath scarcely descended from the top or face of the cone; when the head, *i. e.* the narrow and moist end, is not evenly drawn off to a line; it is concluded that the sugar is over-boiled, or of an ill quality; the syrups are not in a state of digestion; and time is given, and heat added, to make them fit to receive the clay. On the other hand, if the moisture is shrunk and settled, and of a pale colour just round the apex of the cone, there is reason to apprehend that the sugar is under-boiled, or too free; in which case the surface or coat will appear loose, and want that smoothness which the well-boiled loaves exhibit. When this is the case, they must be lightly clayed, and care must be taken that the clay be not too thin or wet. Before the clay is laid on, the thin crust, which had been formed round the edge of the mould by the motion of the hauling knife, is scraped from each loaf into the receiving box, and by pressing the face of the loaf with that part of the hand which is nearest the wrist, a small concavity is made for receiving the first clay, as well as a proper solidity to the bed on which it is intended to rest.

The first or green syrup is now taken away, and poured into large earthen jars, called *gathering-pots*; and the empty pots are returned to receive the moulds which had been taken from them. When they are returned to their proper places, a small ladleful of wet clay is poured on the face of each loaf. This first or green clay dries up in five or six days, and forms a cake, which is taken off, and laid by for future use. When the clay is removed, the whole surface of the loaf will be found to have shrunk under it, and the loaf is become concave in the middle. With a tool, called a *bottoming-trowel*, the sugar which adheres to the sides of the mould is cut away by a horizontal movement: and a small quantity of scrapings, or of lumps broken down for this purpose, is added to the loose sugar which the trowel had cut; and they are pressed down together on the surface, till the whole has been brought to a good level, and to a moderate degree of firmness for bearing the next clay.

On the following day the loaves are clayed a second time; and when this clay is dry, it is removed, like the former; and each loaf is drawn out of its mould, and carefully examined; and this part of the process is called *overseeing*. Double loaves, fine powder loaves, and fine single loaves, will sometimes, under this clay, be found *neat*, *i. e.* the redness or brownness will have quitted the loaf, and the head, though still moist, will appear perfectly free from discoloration. The workman, however, in order to be farther satisfied, cuts off the heads of two or three loaves with the trowel; and if he is satisfied, these loaves are to be clayed no more; but he proceeds to the operation of *brushing-off*, *i. e.* of scraping off the irregularities and impurities occasioned by the contact with the clay with an iron tool, called a *brushing-hook*; and with one corner of this a number or letter is scratched upon the level face of the loaf. To those loaves which are not found neat, the workman gives a third clay; which is usually laid on in a thinner mass than the former. If his loaves are not yet quite finished, he puts a little fresh moisture on the back of the overleaved clay, and thus effects his purpose.

The loaves being now rendered neat, and brushed off, must stand some days in the moulds to acquire *face*, or that stony hardness of surface, which will enable them to stand firm, when they are turned down out of the moulds; and during this time they are once or twice loosened in the moulds by a gentle blow on a stool, or against a post; and thus the coats are improved by preventing adhesion to the moulds, and facilitating the precipitation of the remaining moisture. The

windows are opened to let in air, if the weather be dry; and the points or noses are also examined, which will sometimes melt away, whilst the above operation is effecting. When these symptoms appear, the workman proceeds to turn down his loaves, by taking the moulds from the pots, covering the floor with clear brown paper, and turning each loaf down with its mould over it. They are usually turned down either upon the stove-head, or in some warm place, because by being left uncovered, and exposed to the action of cold air, the moisture remaining in the head will not descend into the body of the loaf, and be equally dispersed; but remaining in the head, would spoil and disfigure the loaf; partly by the syrup's coagulating, and becoming unfit to descend between the fine interstices of the concrete body, and partly from the adhesion of the solid particles. With these precautions, in twenty-four hours the moisture is apparently dispersed, and the cone assumes throughout an uniform appearance. The loaves are then taken off the floor, separately examined, and cleared of any discoloured specks with a small knife; and are either papered and set in the stove, or else are placed in the stove without paper, as the case may require. If any of them have still a remaining yellowness in the head, the point is cut off, and they are then called *spot-loaves*. They remain in the stove five, six, or seven days, till they are entirely dry, and are then fit for sale and use. The management above stated in the course of this one day's work is nearly the same, whether the sugar be fine or coarse.

Brown sugars, wrought in large moulds, require more clay than fine sugars in small moulds: nor is it necessary that lumps should be made neat; but it is the constant practice to cut off the wet head from every lump, so as to leave no remaining redness; these wet tips, called *lump-headings*, are received into a large mould, and placed upon a pot to drain, and when dry, are melted for making double loaves, or for improving powder loaves; or else they are bruised and mixed with brushings to *bottom-up*, i. e. to defend the face of loaves, or other goods, before they receive clay. Large lumps frequently need claying four times. And it may be observed in general, that sugars of every kind require more heat to bring them forward, as they sink in quality.

The materials for double-loaf boiling are made from refined sugar, and frequently from loaves or lumps bought for that purpose. But those who are most curious in this fabric, chuse to make lumps for this purpose, which are called *mellers*: they are low boiled, and stirred but little (though some boilers stir them much), in order to preserve the strength of the sugar unimpaired. Fine double loaves are kept in a room of the temperature of a common parlour; a little warmth is sufficient for powder loaves, and fine single loaves; inferior loaves, and lumps of a middling quality, require warmth; but the brownest lumps and *baftards* thrive in a glowing heat. Every sort of refined sugar will bear and require more heat in proportion as it is higher boiled; for the brown syrupy matter will not quit the denser, unless it be kept in a fluid state; and this can only be effected by the action of heat; and, moreover, the fluid parts of high-boiled goods must be more viscous than those of goods which have been less bound up by fire.

The syrups, which are discharged from refined sugar during the operation of draining, exceed in bulk and weight the whole quantity of loaf or lump sugar, and are, therefore, of great importance in this manufactory; and upon the proper management of them much of its success depends. It will be proper, therefore, to pursue the enquiry relating to the use of syrups, produced from a day's work of sugar once refined in loaves. When the loaves are pre-

pared to receive the first clay, the syrup is collected into gathering-pots, each of which contains from 50 to 60 pounds of syrup; this is called *green* syrup, on account of the new or green state of the loaves from which it runs; and the quantity of it is usually about 15 gathering-pots from each pan of goods. The next syrup, called *second runnings*, is commonly collected when the second clay is removed, and amounts in quantity to about eight gathering-pots *per* pan. The third and last collection is made after the moulds are finally removed from the pots; it is called *drippings*, and is about five gathering-pots *per* pan. However, some workmen collect their syrups oftener than thrice. The syrups of every kind of refined sugar increase in fineness and value, the later they exude from the moulds. As for the appropriation of them, the green or low syrups are boiled away on the days next after the conclusion of refining: they are taken into the pans without the addition of any sugar, and after a sufficient evaporation are poured into large moulds; and under the name of *baftard* sugar, form a principal article in the sugar-trade. The finer syrups are all incorporated with sugar, and a proportion of them is daily brought down through the syrup-pipes into the cistern, at the same time in which the sugar is first skipped from the pans; the syrup-pipe discharging its contents into the clarifying basket, so that the syrup, as well as the sugar, passes through the blanket; and it is pumped back from the cistern into the pans.

The following estimates exhibit the quantity of syrup that may be allowed (*ceteris paribus*) to a given quantity of sugar; viz. for double loaves, six gathering-pots *per* pan; for powder loaves, 10 ditto; for fine single loaves, 15 ditto; for middling loaves, 20 ditto; for brown single loaves, and Canary lumps, 25 ditto; for lumps, 30 or 40 ditto.

With the necessary allowances for particular circumstances, the several sorts of syrups may be duly appropriated in the following manner. Green syrups of every kind may be mixed with raw sugar, or applied to the making of goods, two degrees in quality lower than those from which these syrups were produced. Second runnings of every kind are fit to be incorporated with goods one degree below those from which they were produced. Drippings may be used with raw sugar, or with other proper materials, in making the same kind of goods from which they had been supplied. In other words, the green syrup of double loaves would be used in making single loaves; the second runnings would go into the composition of powder loaves; and the drippings would enter into the substance of other double loaves. Again, the green syrup of large lumps would be boiled off in *baftards*; the second running would make *pieces*; and the drippings, added to proper sugar, would be united therewith in the production of other lumps.

Pieces are a better kind of *baftards*, which are either boiled from syrups that are too good to make *baftards*, or are made of such syrups, and a small portion of cheap and bad sugar, which is too poor to make lumps. In the latter case, they are called *sugar-pieces*; but in either, all the syrup that comes from them is boiled again, either to make *baftards* or other pieces, according to its goodness; whereas the syrup that runs from *baftards* is always considered as a *caput mortuum*, and no efforts are made to obtain any sugar from it, but it is put into casks, and sold under the denomination of *melasses*. It is, therefore, worth the boiler's attention to keep all the weight of sugar possible in his *baftards*; and for this purpose he boils them as high as he may venture, without incurring the danger of making stopped *baftards*; i. e. *baftards* from which the *melasses*

will not run; which may be owing either to the ill quality of the materials, or to overboiling. But as the syrup of pieces is to be boiled again, a good workman never exhausts it by overboiling. The materials of which bastards and pieces are composed, not abounding with salts like those already treated of, have not an equal disposition to concretion; and, therefore, it is found necessary to give them some aid, in order to effect the necessary granulation: this is done by taking *grain* (which we shall presently explain) into the coolers. These inferior productions are stirred, neither in the coolers nor in the moulds, any more than by a small movement round the coolers, with an iron scraper, just sufficient to incorporate the grain with the hot fluid mafs.

In order to illustrate the formation of this grain, we may observe, that the strong particles of sugar, which are capable of concretion, have evidently a greater degree of density than the oily or aqueous. When the hot fluid is poured into a bastard or piece mould, these denser particles descend, and would pass into the pots if there were any passage for them; but the stopper is not taken out of the moulds of these goods until five, six, seven, or eight days after they have been pulled up; for they want time to harden, and cannot safely be left unflopped. Having reached the lower part of the mould, they are formed into small stony substances of the nature of candy, and when the stoppers are withdrawn, these small stones remain near the point of the mould, and form what is properly called *bastard grain*.

Bastards and pieces are usually clayed but twice, and when dry enough, are knocked out of the moulds, their wet heads being cut off into a large mould placed to receive them, and they are called *bastard-heading*, or *smear*; in another mould is preserved the grain, which usually forms a stratum about two inches broad, beginning about four inches from the point of the mould. The bastards and pieces are then put into the stove, and in five, six, or seven days, will be found dry enough; for they must not, like lumps and loaves, be rendered perfectly dry. They are then taken out and piled in a room, as near the mill as possible, and ground all together; or the brown tip is cut off, and the other two parts, called the *middle* and *face*, are ground together: or sometimes the bastard or piece is divided into three parts, which are ground separately, and sold at different prices.

We shall now close this article with a short account of the method of making over *scums*, and the application of their produce. The refiner extracts from the scum of his sugars, every particle of sugar which it is in his power to obtain; and after he has reduced the scum to such a state that it appears to be a mere earth, resembling garden mould, he sells it to a scum-boiler, who again tries it over the fire, and extracts a small quantity of sweet liquor out of it. The scum of fine treble or double loaves is often put into the pans again without any process, and mixed with raw sugar, for the production of inferior goods: but, in general, the scum of each day's work is made over in the same day after the boiling of the sugar is finished. The method is this; the panman, having put about three quarts of spice into his pan, draws lime-water until the pan be four-fifths full without the pan-brace; to this he adds about four tubs of the scum, each tub containing about three-fourths of a hundred-weight. Having stirred the liquor well, he makes a moderate fire, and the scum will separate from the fluid and float upon the top of it: with a small iron scraper he prevents any foulness from adhering to the bottom of the pans; and then suffers the fire to increase, and the liquid, upon the verge of boiling, is seen through the open-

ings of the dirty surface. Having kept it simmering for several hours, and having provided a cooler or receiver, over which is placed a strong wooden frame, and upon this a basket, to which a coarse bag, called the *scum-bag*, is fitted, he pours the contents of his pan into this basket and bag; and then the mouth of the bag is drawn up, and well twisted together, and a strong board, called a *scum-board*, is laid upon the bags, with several weights upon the board, to press down the scum. In the space of an hour, or an hour and a half, the bag should be twisted and pressed; and the liquor, which oozes plentifully through the bag, is usually taken into the pans the next morning: its thinness renders it useful in clearing the pans, and if any gross matter hath passed through the bags, it is drawn off with the rest of the scum of the sugar when cleared. The scum, as it is taken from the pan, is called *fat scum*, and the liquid matter drawn from it bears the same appellation; in contradistinction to the poor meagre liquor which is expressed from the same scum when they are made over a second time, by an operation much like the former. After pressing and draining, the exhausted remains, under the name of *rubbish scum*, are either burnt in the cockell, or delivered to the scum-boiler at a very low rate. The produce of over-made scums must be used immediately, or it must be shortened, *i. e.* boiled thick; otherwise it will turn sour and do great harm; for acidity is a constant enemy and destroyer of sugar.

The liquor drawn from these scums is commonly used in bastard boiling, or in the brownest lumps. There is a large proportion of the fat scum usually left of every refining, to be made over during the bastard boiling: it is common to set by the first or grossest scum for this purpose, and to keep separate the finer and later scums, which are made over day by day in the manner already described: the liquor thus obtained from the fat scums, being full of sugar, is very useful to the bastards, fortifying the syrups, and promoting their strength and adhesion. The editor is indebted for the materials which have supplied this article, and those on the manufacture of sugar-candy, and the construction of a sugar-house, to the kind communication of Mr. Griffin, an eminent sugar-refiner in London.

Of the improvements that have been made in the processes for refining of sugar, we shall give an account according to the order of time in which the patents were granted.

In October 1812, Edward Charles Howard, esq. of Westbourn Green, in the county of Middlesex, obtained a patent, the specification of which informs us, that he has established and adopted the following operations. In the first instance, he submits raw or muscovado sugar to a primary operation, by well mixing, as expeditiously as possible, the said sugar with such a quantity of water as will, at the common temperature of the atmosphere, bring it to a magma of the consistency of well-worked mortar: having left it at rest for the space of an hour or more, he heats it to a moderate temperature, *e. g.* from 190° to 200° Fahr., which is most conveniently effected in a vessel surrounded by boiling-water or steam, under the common pressure of the atmosphere; he then adds more sugar, or a thinner magma, so as to render the mafs imperfectly fluid, and fills the moulds with it from the water-bath; and when it is become cold in the moulds, he takes the stopper out of the mould, and suffers the melasses to drain from it. When the drainage is completed, he pares down the large or upper surface of the lump, loaf, or mafs of sugar remaining in the mould, with any fit instrument, until the sugar presents an uniform appearance. He next mixes the sugar so pared off with

cold water, till the magma acquires a consistency, which will not allow it to readily close behind the sizar; and then replaces it, in that condition, upon the uniform and firm surface before prepared; and as soon as the magma becomes moderately dry, he pours upon it, with the intervention of a float or similar guard, a cold saturated solution of fine sugar in cold water, about half an inch deep; or, he takes off the said magma down to the surface of the lump, loaf, or mass, left after the first paring, and remixes the same with water to a thinner consistency than last-mentioned, and again replaces it as aforesaid; and he repeats the said operations by this magma, or with a cold saturated solution of finer sugar than that which he intends to refine, according to its nature or quality. He farther declares, that when the sugar proves extremely close-grained, and the surface extremely hard, an unsaturated solution of sugar, or even water itself, may be poured on it, without running in: but this process requires too much nicety for general practice. When the sugar proves open-grained, the finer the sugar, made into magma, is ground, the better, because the moisture is thereby prevented from descending too fast or unequally into the loaf. It is not necessary, that the sugar taken from the surface of the loaf should be used as magma or syrup upon it.

The fit time for terminating this primary operation is ascertained either by drawing from time to time one of the lumps, loaves, or masses so prepared, or by observing the greater or less freedom with which new moisture is admitted, and the colour of the melasses dripping out. It is farther declared, that it is most beneficial in conducting this process, to leave the temperature of the place or apartment in which the moulds are placed, previously to their being treated with the magma, to about 60°, and again to raise the same to about 80° or 90°, after the surface of the loaf becomes dry for the last time. It will be necessary, in every case of the percolation of melasses or syrup, to pierce, perforate, or break the dry surface of the mass of sugar in the moulds, when it is become so solid or iced over as to prevent the access or escape of the air into or out of the sugar, and thus to impede or prevent the flow of the melasses or syrup.

This primary operation being finished, the operator does in the usual manner break or draw out the lumps, loaves, or masses, and separate the net or good sugar from that which retains melasses, reserving this latter to be mixed up with raw sugar, for a subsequent preparatory operation, such as has been already described. The former is then refined by pouring upon it, in any convenient vessel, 6lbs. of water (boiling-hot) to every 5 lbs. of sugar, deducting about 6 per cent. for the moisture previously contained in it; and having insured a perfect dissolution of the sugar, by stirring, the impurities are allowed to subside, and then the solution is drawn off from the said impurities into another clean suitable vessel; and in order farther to clarify and separate impurities and colouring matter, the ordinary finings are added. These finings are prepared by slaking well-burned lime with boiling water, so as to obtain a cream of lime; to this is added about an equal bulk of water, and the mixture is boiled for some minutes, until the lime assumes the appearance of fine curd: the extraneous matters or lumps, always contained in lime, are separated by washing over, or, as the chemists term it, by the process of elutriation; and that this may be done effectually, the lime and liquor so washed over, are made to pass through as fine a sieve as will admit the passage of the finest curds. The next part of the process is to dissolve about 2½ lbs. of alum for every cwt. of solid sugar that is to be refined in

about 16 times its weight of water, and to add to such solution about 70 or 80 grains of whiting for each pound of alum; and after stirring up the mixture till the effervescence ceases, the suspended substances are allowed to subside, and the solution is drawn off from the precipitated matters, and then are put into it the prepared lime-curds, shook up with the water they retain (the whole being agitated during the effusion) in such quantity of the curds, so that paper stained with turmeric shall barely change its colour by immersion in the mixture, and shall recover its former yellowness when dry, and shall, by immersion in the clear supernatant liquor, after subsidence, be scarcely changed at all. The finings, thus duly prepared, are suffered to settle to the bottom of the containing vessel; and after draining off the supernatant liquor, the said finings are placed upon blankets, supported in the manner of a filter, and the moisture is drained off till the mass begins to contract, and separate by cracks in it; and in this last state the said finings are fit for the clarification of the sugar last drawn off, as above described. Such a quantity of that solution, or of any other similar solution of sugar, is added by degrees, and with stirring, as will bring them to an uniform creamy state. This mixture is then poured into the whole quantity of the said solution of sugar prepared or intended for clarification as aforesaid, with sufficient agitation for diffusing the finings equally.

The refined or clarified sugar is then suffered to remain, either during the night, or for about six hours, and the bright liquor drawn off from the finings, in the usual methods; and an evaporation is commenced and carried on at the temperature of about 200°, which is best effected by the heat of steam, or water under the common pressure of the atmosphere, until the hot liquor shall have acquired a specific gravity of about 1.37 (that of water being 100), and in this state the same is transferred to any convenient vessel, and stirred frequently, until it assume the proper granular consistency to fill the moulds, and accordingly the moulds are filled with it. The stoppers are then taken out from the moulds as soon as they become cold, and the syrup naturally contained in the lump, loaf, or mass, is allowed to run off from it in the usual manner: during the said operation, and when the syrup has left the upper surface of the lump, loaf, or mass, the same is pared down, as before described; and if the sugar appear sufficiently fine for the intended consumption or market, it is taken out of the mould, after it ceases to drip, in the usual manner, the smaller end of the loaf not clear of syrup being cut off; and it is then dried in the ordinary mode. But if the lump or loaf be not sufficiently white, the sugar before pared off the surface is mixed up to a magma with water, as in the primary operation. If the loaf, as above prepared, be not sufficiently dense or close in its grain to satisfy the consumer, the loaf, previously to drying, is remoulded, according to the usual practice, by stamping the grains into a metallic or other mould, which will immediately redeliver the same. If it be required to retain the point of the lump, loaf, or mass, without returning the syrup contained in that point upon its body, this desideratum is effected by the appendage of a pipe, applied and fixed to moulds of the usual construction, having the aperture enlarged to one inch at the least, or to form part of a new mould, which is to be fabricated on purpose; then the lower portion of the sugar is taken off, which will be contained in the said pipe, along with the redundant syrup, instead of taking off the point as usual.

To the first of the liquors left in the two cisterns or other vessels which contain the insoluble impurities, is added about its bulk of boiling water, and it is then passed through

a cloth sufficiently close in its texture for retaining the gross impurities; and the second liquor, containing the above-described finings, is added, abstracting from them, by washing and subsidence, all the sweet they contain; which sweet liquor is used for magma. The syrups, which drain from sugars which have been subjected to the action of finings, may be evaporated without any addition, provided the boiling temperature be avoided by means of the steam or water-bath above-mentioned; and such syrups will, by such treatment, afford strong crystals a second, third, or even fourth time. Or, otherwise, sugar remaining from top-parings, cut-off points, or any other remnants, may be melted in them, upon the water-bath, to bring the same up to their crystallizing density or granular consistency: and the inferior syrups may be advantageously mixed with muscovado sugar instead of water, in the manner stated in the account of the primary operation.

The lumps, loaves, or masses of sugar which have been refined by the use of the ordinary or common finings, or any other sugars in a forward state of refinement, may be farther refined by the application of other finings, prepared in the following manner; *viz.* by dissolving about three pounds and a half of alum for every hundred weight of solid sugar, in about sixteen times its weight of boiling-hot water, and adding to such solution about seventy or eighty grains of whiting for each pound of alum; and after stirring up such mixture till the effervescence ceases, allowing the suspended substances to subside, and drawing off the solution, pouring into it (instead of the lime-curds in the ordinary finings) a concentrated solution or ley of caustic soda, until the agitated mixture shall produce a very slight stain upon turmeric paper; and then adding to it the fairest water, washing the precipitate by alternate diffusion and subsidence, until the water comes off tasteless, and then drawing off or draining the remaining water from the finings, as before described. The water is often purified by the well-known process of boiling it with a small quantity of alum, and a little lime or chalk, taking care to leave no excess of caustic lime in solution. It is observed, that a compound of lime and alumine would answer the purpose of the first finings, and that pure alumine, howsoever obtained, will answer the purpose of the second finings; and that caustic lime is preferred to potash, because the salt resulting is most easily washed away, and to ammonia, because this last is an article of great price. In the specification it is added, that the superior degree of refinement in solid sugar (already refined to a forward state) is produced by dissolving the sugar intended to be refined, in the fairest water (boiling hot), in the manner and proportion already described. Subsequently to his preparatory operation, and immediately upon the solution being effected, the patentee mixes and diffuses his second finings as the first finings were directed to be mixed and diffused, and after due clarification by repose, he proceeds to the evaporation and subsequent completion of the sugar in loaves, as before directed and prescribed in like cases. He farther declares, that in the application of heat to the refining of sugars, he makes use, in certain circumstances, of higher temperatures than those stated (although less beneficial), taking care to preserve an uniformity in the application of the heat to the surface of the boiler. For temperatures above the boiling point of water, he makes his steam-bath strong, and capable of being properly closed, and provides the same with a feeder under due pressure, or a forcing-pump for feeding, and a safety-valve and pipes of communication, cocks, and gauges, and all or any of the needful fittings-up, which are commonly used with steam-boilers. It is farther remarked, that if it be required to

use the ordinary or common finings to very coarse moist or deliquescent sugars, it will be necessary to add a greater proportion of the lime-curds than that which has been prescribed with regard to sugars partly refined by percolation or otherwise; and making the said addition, the judgment of the operator must be directed by the quality of the said coarse moist or deliquescent sugars. The patentee further declares, that his invention, and the several manipulations of it, may be practised, wholly or separately, without or in conjunction with the methods of refining sugars already in common use. Mr. E. C. Howard obtained another patent, dated Nov. 20th, 1813, for certain improvements in the processes described in the patent granted to him October 31st, 1812, and certain apparatus for carrying the same into effect.

A patent, dated May 8th, 1815, was granted to Peter Martineau the younger, of Canonbury-House, Islington, and John Martineau the younger, of Stamford-Hill, gentleman, for a new method or methods of refining or clarifying certain vegetable substances. In their specification they declare, that if their invention, so far as relates to animal charcoal, be applied to vegetable acids, such as are usually prepared or manufactured in a crystallized state, or other vegetable substances, the process should be the same as is hereafter described, excepting only that as blood may be advantageously used in refining sugar, it is not necessary for refining other substances, from which the articles which they employ may be separated by filtering in common and well-known methods.

The articles employed by the patentees for purifying and clarifying sugar, are, 1st, animal charcoal; that is, animal substances, properly burnt, or charred, or calcined, such as ivory-black, bone-ash, &c. and afterwards reduced into smaller pieces or powder. 2dly. Bituminous earths, commonly called coals, either in the state in which they are mined, or articles of their products after fusion, and reduced, as before-mentioned. 3dly. Certain argillaceous earths, known by the name of ochres. 4thly. The vegetable charcoal, usually called lamp-black. The first-mentioned articles, however, are preferred in the process of refining and clarifying sugar, which render the sugar so clarified much whiter than by the heretofore common method of clarifying. The following method of applying the above-mentioned substances is preferred. We charge, say the patentees, or fill our boilers or pans with sugar and water, or lime-water, as in the common and well-known methods of refining sugar, only sometimes preferring to add a little more water or lime-water than in the common mode of refining, as it generally more easily and effectually separates the animal charcoal, or other substances, from the liquid sugar. And we also add to the above sugar and water in the boiler the substances before-mentioned, in any quantity, according to the quality of the sugar to be refined or clarified; though we generally prefer from two to five pounds of charcoal or earths before-mentioned, to and for every hundred weight of sugar to be refined or clarified. And, farther, we pour into the boiler the usual finings of eggs, blood, or other albuminous matter, in rather larger quantities than in the usual mode of refining, in order, in some degree, to coagulate and combine the animal charcoal, or other substances, with the dirt contained in the sugar. We now well stir up and agitate the liquor in the boiler, in order that the animal charcoal, and other substances, may have the greater effect in blanching the liquor. And after the coagulated albumen has completely risen in the form of scum by the application of heat, in the usual way, we either skim it off, as in the common process, or we pour the whole of the liquid sugar and scum into and upon

the usual or any other known filter, when this clarified liquor is completely separated from the albuminous matter, as well as from the animal charcoal, or other substances employed; taking care to return back into the filter the first runnings of the said liquor, if not quite separated from the above substance used. And, further, we proceed in the usual manner to evaporate, granulate, and refine, the said liquid sugar so clarified. And, further, we boil over and filter our scum in the usual manner. We further declare, that the sugar so clarified and refined is preferable to sugar refined in the heretofore common mode, inasmuch as it is purer and whiter. And we further declare, that the syrups obtained by this process have not that tendency to ferment which the syrups have which are produced in the heretofore usual method.

A patent, dated June 22d, 1815, was granted to John Taylor of Stratford, in the county of Essex, manufacturing chemist, for a method or methods of purifying and refining sugar. The patentee, in his specification, declares that his invention is applicable to the purification and improvement of raw sugars, if employed in the original manufacture in the West Indies; or that the said raw sugars, as now commonly imported into this country, may thereby be improved in quality here, so as to render the subsequent operations of refining less complex and expensive than when raw sugar not so purified is employed. The patentee states the nature of his invention to be as follows: "I have found that the melasses and other soluble impurities contained in raw sugar may be separated therefrom by mechanical means, without the use of heat; and that by abstracting these from the raw sugars, the injury caused by their mixture with the refined sugar in crystallizing is avoided. For purifying raw sugar according to my invention, it must first be brought to a moist state; and if the process be employed in the original manufacture in the West Indies, the degree of moisture at which the sugar will be upon draining a short time after it is taken from the coolers in which it is crystallized, will be sufficient. But if my said invention be practiced in this country on sugars as dry as they are usually imported, they will require to be mixed with a certain proportion of cold water, or lime-water. This proportion may be varied according to the opinion of the operator and the quality of the sugar, and will readily be determined by trial, as no exact rule can be laid down for each case:—in general, the proportion of water may be from one-eighth to one-tenth of the weight of the sugar. The sugar and water are to be well mixed in any proper vessel, and the whole is then to be subjected to pressure, carried to such a degree as to express all the fluid part therefrom, which will be found to contain the melasses and soluble impurities, and a certain quantity of sugar in solution; and the sugar, if the pressure be sufficient, will be rendered dry, and much improved in colour and appearance.

"I further declare, that though my invention may be carried into effect in a variety of ways, by using presses of various construction, and by exposing the sugar to pressure in a variety of modes, yet that the following operation is the one which by preference I adopt. After the sugar has been mixed with water, or otherwise moistened, I inclose it in strong linen or woollen cloths, each of which is cut about thirty inches square, and being laid over a wooden box twelve inches square and two inches deep, some of the moistened sugar may be pressed in, and the cloth folded round it so as to form a square cake. A press is to be constructed with a platform, capable of containing at least four piles of these cakes, which may be arranged so as to stand at a certain height, and may then receive a degree of pres-

sure, which will cause the fluid part to flow out, and which is to be received in a copper pan, fixed upon the platform of the press, and furnished with a spout, to convey the expressed syrup into a receiving vessel. While these cakes are pressing, another set is to be got ready, and the first having been hardened with pressure, may be adjusted so as to keep the piles upright, and the fresh cakes set upon them, and so exposed to pressure. In this way a considerable quantity of sugar may be got into a press, and, after having been moderately hardened, the whole should be taken down, and again set up, and exposed to a higher degree of pressure, which will render the whole dry, and of uniform good colour and appearance.

"I further declare, that any machine or apparatus is capable of applying pressure to sugar, either vertically or horizontally; and whether the sugar be inclosed in cloths, as I have described, or in bags, or in cases, frames of wood, metal, or other materials, may be used for the purpose of my invention; but that I prefer the mode I have herein pointed out; and that I have found the hydrostatic presses, and commonly known by the name of Bramah's presses, most convenient for the purpose.

"And I further declare, that the sugar prepared and purified in the way I have described is much improved, and may be refined into lump-sugar by any of the processes for that purpose, and with less expence and trouble, and in less time, than is required for raw sugar not so purified. And further, that if my said invention be applied to the original manufacture of sugar in the West Indies, the sugar so prepared will be fit for immediate shipment, as all the time required for draining and drying will be saved, and all danger of fermentation prevented.

"And I do further declare, that the sugar contained in the expressed syrups may be obtained therefrom by the usual processes of evaporation, and from its not being injured by the usual application of heat, is capable of being made into an inferior sort of refined sugar."

SUGAR, *Barley, Saccharum Hordeatum*, is a sugar boiled till it be brittle, and then cast on a stone anointed with oil of sweet almonds, and formed into twitted sticks, about the length of the hand, and the thickness of a finger.

It should be boiled up with a decoction of barley, whence it takes its name; but, in lieu of it, they now generally use common water, to make the sugar the finer. To give it the brighter amber colour, they sometimes cast saffron into it. It is found very good for the cure of colds and rheums.

SUGAR-Candy, *Saccharum Candum*, or *CrySTALLINUM*, is sugar depurated and crystallized, and differs from common sugar in being much harder and transparent. See CANDY.

The sugar to be used in this process is first dissolved in a weak lime-water, then clarified, scummed, strained through a cloth, and boiled, and put in forms or moulds, that are traversed with little rods, to retain the sugar as it crystallizes. These forms are suspended in a hot stove, with a pot underneath, to receive the syrup that drops out at the hole in the bottom, which is half-stopped, that the filtration may be the gentler. When the forms are full, the stove is shut up, and the fire made very vehement.

Upon this, the sugar fastens to the sticks that cross the forms, and there hangs in little splinters of crystal. When the sugar is quite dry, the forms are broken, and the sugar is taken out candied. Red sugar-candy they make, by casting into the vessel, where the sugar is boiling, a little juice of the Indian fig; and if it is desired to have it perfumed, they cast a drop of some essence in, when the sugar is putting into the forms.

This method of making sugar-candy is that of F. Labat, practised in the Caribbees.

The method among our manufacturers is as follows. A stove is set apart for this purpose, the entrance into which is in the ground floor, and as near as possible to the pans; and the top is usually from ten to fourteen feet above the ground, and covered like the top or crown of an oven. Beams are fastened into the walls, at the distance of about twenty-six inches from each other, and sufficient to bear a very large weight: upon which strong planks are laid when they are wanted, and upon the planks the candy-pots are set: when the stove of candy is finished, the planks are removed. The pots are usually made of thin copper, without feet, and with an iron rim round the top, to strengthen them: the bottoms are hammered into the most perfect flatness, that they may stand firm and steady: they are perforated in rows on two sides with holes about one-tenth of an inch in diameter. According to the old method of piercing, the holes were very close laterally, and the candy of each string united with that of the next, and the whole formed a strong cake: but according to the improved method, the holes are kept at a proper distance apart, *i. e.* at the distance of one inch and a half in the upper rows, and widening downwards to two inches; and the candy is formed in distinct bars, more convenient for package and sale, and much more beautiful than the former.

When a stove of candy is intended to be made, the cockell should be moderately heated, at least twenty-four hours before the operation begins; and the candy-pots are strung, *i. e.* a coarse white thread is drawn by a needle through the first hole of the bottom row, and the end being fastened there, the thread is led across the inside of the pot to the opposite hole, and continued from side to side, till that row is finished: the next row above it is then strung in the same manner, &c. till every row is finished. The pots, being all strung (*viz.* about forty to each pan of sugar), must be palled, *i. e.* the holes must be stopped either by palling papers over them on the outside, or by brushing any glutinous matter over the outside. When the stoves and pots are ready, the workman places five pots upon the pavement, beginning either at the right or the left-hand corner of the stove opposite to the cockell.

The management of the pans is nearly the same as has been described under *Refining of SUGAR*, with some small difference. The sugar intended for candy should be cleared with less water than other goods: the lime-water for brown candy should be of the greatest strength; and the workman endeavours to extract the scum as soon as possible, because it is imagined that the strength of the sugar may be impaired if it be suffered to lie too long dissolved. No scum is ever incorporated with the sugar intended for candy; indeed four or six gathering-pots to a pan are sometimes taken; but it is apprehended, that it would be better to omit even this. The sugar melted for candy should be the strongest that can be obtained.

When these precautions have been observed, let us imagine the sugar cleared off and skipped into the cistern. The panman pumps back about the usual quantity: the boiler carries the evaporation to the point he judges proper; and it is immediately skipped off into basons, which are carried directly to the stove; and the pots are then filled in the following manner. The fill-house man receives the first bason, and pours its contents into N^o 1, proceeds to N^o 2, and so on, till he has reached N^o 5; and then proceeds to fill N^o 5, 4, 3, 2, and 1. When this set is filled, the fill-house man goes on till he has covered the whole pavement: he then lays two planks upon the lowest beams, and places a series

of pots upon the farther one, standing upon the other to fill them: he then lays down another strong plank, and covers that on which he stood, and so proceeds to build up row after row, till the whole is finished. In the whole progress of this business he moves slowly and cautiously, and causes all the doors to be shut, so that no currents of air may approach him; as stillness is of the greatest consequence, and the least concussion of the air is sufficient to disturb and break the crystallization. When the pots are filled, the stove-door is fastened up, and covered with a blanket, or stopped with wet clay. The cockell is stoked to such a degree, that the candy may stand in a blood-heat; at the end of six or seven days, the crystallization of brown candy will be complete. The pots are then removed from the planks and the floor, and the operation commences, which is called *stirring*, or *breaking-up* a stove of candy. Each pot is brought to the side of a cooler, upon which, over a frame, a clean basket is laid, into which all the sugar that has not crystallized is poured off, and along with it the *crust*, which is a coat of candy, that had formed itself upon the surface: the syrup or uncrystallized sugar runs through the basket into the cooler, but the crust remains in the basket, in which it is washed and dried, and afterwards packed for sale with the candy. As soon as the syrup is poured off, the pot is brought to the side of the pan, and ladles of clean water, blood-warm, are poured in till it be nearly filled; the pot is then smartly shook round, and the water is returned into the pan. The candy being thus worked, the boiler examines it. If it be strong and good, it presents a beautiful appearance; the sides of the pot are every where covered with a coat about half an inch thick, the front of which is cut in flarry forms, reflecting the light in various directions; and upon every line the crystals fasten in the most varied and capricious forms. If the pots were pierced, as they formerly were, so that the strings might lie but an inch asunder, the candy of each line would then run into the next, their sides become united, and the whole form a strong cake, not to be separated without force: but the modern improved pots are so pierced, that the crystals are suspended upon every thread in distinct bars, without either lateral or perpendicular cohesion.

The washing above described is necessary to cleanse from the face of the crystals every particle of syrupy matter, which would otherwise occasion a clamminess in the candy, and obscure its lustre. After washing, each pot is turned down into a cooler or other receiver, to drain, and when they are washed and drained, they are again put into the stove to be dried; for this purpose they are placed in the stove aslant, resting against the wall, or against each other, with the mouth downwards; and under each pot is placed a small earthen pan, called a *candy-lafon*, to receive the remaining moisture which will drip from them: the stove is again fastened up, and the cockell stoked, so as to produce a fierce fire, which must be well kept up for three days: at the end of which time the candy will be dry enough to quit the pot; they are therefore taken out of the stove, and turned down upon the floor, previously covered with clean paper; and with a little shaking, or a gentle blow, the whole mass of candy quits the pot, retaining the form of it complete: and then the candy is returned to the stove for the third and last time, where in three or four days, with a good fire, it will become perfectly dry, and fit for sale. It is generally packed in boxes of about fifty-six pounds each: at the bottom of the box is a layer of the bottoms of the pots, which have the least beauty or fineness; then a course of bars of candy, upon that a stratum of crust, and so on to the top of the box, finishing with bars of the handfomest

candy, neatly laid with the face upwards. At the bottom of the candy there are often found masses of sugar which hath not yet crystallized, but is become concreted in small round grains, of a lighter colour than the candy; this is called *foot*, and is either sold at a lower rate, under the name of *candy-foot*, or melted with other sugar, for the making of lumps and loaves. The syrup of candy is fit to be taken copiously with raw sugar in lump-boiling. The washings and the drips from the bafon are applicable to the same uses.

White-candy is made like the former, but from fine lump or loaf sugar, cleared as for double loaves. It is boiled to lower proof; stands in a milder warmth; forms in three days instead of seven; and the value depending upon the whiteness, it must be managed with the utmost delicacy in every stage of the process.

The *brown* sort crystallizes as regularly as the white, but becomes clammy and deliquescent in a damp air, whereas the white candy remains always dry. On account of its superior hardness, it is less easily soluble than the loaf-sugar, and would be excellently calculated for preserving all vegetable food, if the price was lower. The sole difference between the white candy and the finest loaf appears to be in the form, which in the candy is the natural saline form of sugar, but in the loaf is granular, owing to the agitation given to it for this express purpose whilst cooling. The most common form of the regular crystals of sugar-candy is an oblique four-sided prism, terminated by dihedral summits.

White sugar-candy, and also sugar, are used as ingredients to render water a vehicle for colours in miniature-painting. The intention of using them is to prevent the colours from cracking when mixed with gum-arabic, and also to make the gum-water work more kindly with the pencil. See STARCH.

SUGAR-HOUSE, is a brick or stone building, constructed for a sugar-refining manufactory. A house intended to contain one or two pans should be square, or nearly square; but a house of larger dimensions ought to be of an oblong form; as it may be conveniently heated, by placing the chimney of the stove and of the pans at opposite angles. A house to contain one pan should consist of six floors besides the ground-floor; the dimension about twenty-seven feet square: a two-pan house about thirty-six feet by forty feet: a house of four pans, about forty feet by sixty or sixty-five feet. The stove is a brick building from eight to fourteen feet square, usually placed in one corner of the building. The height of the several stories should be as follows; the fill-house, or ground-floor, nine feet below the girders; the next floor above it, called the *warehouse*, of the same height; and every other floor upwards, six feet at most between the girders and the floor. In every floor must be left an aperture, through which a rope is suspended upon a brass pulley on the uppermost floor for drawing up the sugars: and provided due attention be given to the strength of the building, and to the exclusion of damps and a cold air, a sugar-house cannot be rendered too light. The utensils necessary to a sugar-house are of copper, lead, iron, carpentry, back-maker's work, wicker-work, pottery, &c. The copper utensils are the pans, coolers, cisterns, syrup-pipes, bafons, ladles, skimmers, and, in some cases, candy-pots, &c.

The pans are usually made of a conical form, from five to six feet diameter at the top, decreasing to a diameter of about two feet six inches, or three feet. The coolers are vessels of thin copper, of six feet in diameter, and about twenty inches high: the number of pans and coolers is usually the same. The clarifying cistern is a large receiver, either of copper or lead, placed as near as possible to the sides of the

pans, and capable of containing at least one-third more than the contents of all the pans collectively. The syrup-pipes are tubes of four inches diameter, made of thin copper, or tin-plates, and suspended perpendicularly over the clarifying cistern, from the upper floor through the whole building. The bafons are vessels containing from four to six gallons each, in which the boiled sugar is carried from the pans to the coolers, and from the coolers to the moulds. The ladles are of several sizes. Skimmers are of fourteen inches diameter, pierced with holes like a cullender; and likewise a small one of the same kind. Cullenders are of eighteen inches diameter, and fourteen inches deep, through which the clay is to be strained: and there is also another, which is smaller, for the purpose of straining spice.

The leaden utensils and plumbers' ware, are such as follow: the bench is a ledge about one foot broad, running before the pans, and rising in front, by which it is capable of receiving the sugar which is spilled before the pans. The scum-cistern is a wooden receiver, usually lined with lead, and nearly as large as the clarifying cistern.

The water-pipes are a pewter or hard metal pipe from the lime-cistern to the pans, and leaden pipes for the conveyance of common water or liquor to the pans, and to the lime-cisterns. The pumps are a copper pump fixed in the clarifying cistern, and a spare pump of the same kind.

The iron-founder supplies bars of a triangular form, to be laid under the pans, and the cockell, which is an iron trunk, used to dry the goods in the stove; and also iron doors, stove-doors, and pan-doors, &c.

The carpenter raises the steam-vent over the pans, which is a hood of thin board, so formed as to conduct the steam to the two brick funnels, which are led up on either side of the pan-chimney to the top. He also furnishes the racks of the stove, a trough to convey the sugar from the pans to the cistern, and another to return it from the cistern to the pans, syrup-tools, blocks, cooler oars, &c.

The back-makers supply two or more tubs or backs for lime-water, which are round, oval, or square, and whose capacity varies from thirty to two hundred barrels. The liquor-back, is any vessel large enough to hold a considerable quantity of common water. The mould-cistern is a large oblong vessel, in which the moulds are soaked before they are used: it is usually about four feet six inches deep, and should be capable of containing at once as many moulds as are used in one day's refining.

The clay-cisterns are supplied either by the back-maker or carpenter, and also the clay-flar, which is made of oak or elm, its club end being stuck full of iron points: its use is to macerate and fine the clay.

The wicker-work consists of refining-baskets, scum-baskets, pulling-up-baskets, coal and clay-baskets, &c.

The sugar-mill is one of the most simple machines of the kind: the runner is sometimes made of cast-iron and sometimes of stone: the former is preferable, because a larger diameter and a broader surface may be had with the same weight. The runner and the centre post should have a brass collet within them, for the iron spindle to turn upon. The mill should stand on a solid foundation; either on the earth, or on the centre of a brick or stone arch. The vessels of pottery are of various sizes, and of two different forms and denominations, *viz.* pots and moulds.

The construction of the pan-chimney requires peculiar attention; it should be placed on iron bases, and the horizontal bars on which it rests must be wrought in the walls of the building, and clenched down on the outside. But the setting of the pans is the most difficult work; for it is necessary that they should be so fixed, as that the stones,

which burn away under them three or four times in a year, should be taken out and replaced, without pulling down the whole work.

After all, a principal consideration in the construction of a sugar-house, is the obtaining a sufficient degree of heat. Various degrees of heat are required for different sorts of goods, and occasionally for the same sort: accordingly each floor may be made more or less warm, as the case requires. The heat is introduced through the pan-chimney, the stove-chimney, and sometimes through iron or brick flues raised on purpose. It is communicated from the chimnies by shutting the register-plates, after the fires are extinguished, or when they are nearly out, and the remaining ashes are perfectly clear. After shutting the register-plates, the small iron doors (one of which is fixed in the chimnies both of the cockell and the pans upon every floor) are opened, to convey heat where it is wanted.

Labourers in sugar-houses are very subject to dysenteries: the *vitrum antimonii ceratum* is an effectual remedy in these cases.

SUGAR-Mill, a machine used in the West Indies to press out the juice from the sugar-cane, as briefly described under our article SUGAR, *supra*. The sugar-mill is a very simple machine, consisting only of three vertical rollers mounted in a frame. The power is applied to the centre one to turn it round, and all the three are made to turn together by means of cog-wheels. The canes are introduced between these rollers, which as they turn round draw in the canes and give them a very violent pressure, which is sufficient to extract the juice and leave the canes dry.

Sugar-mills are worked by cattle, wind, or streams of water; and since the improved steam-engines of Mr. Watt have become general, many steam sugar-mills have been sent out to the West India plantations. In situations where a fall of water cannot be obtained, these are preferable to cattle-mills or wind-mills; for if cattle are used, an extra stock should be kept on purpose, because the regular cattle of the plantation are fully employed at the season of cutting the canes. The operations of the mill should be carried on constantly in a regular manner, until the whole crop is finished, or there will be danger of the juice fermenting in the canes, if the machinery is not sufficiently powerful to extract the juice from the canes as fast as they are brought in from the field in bundles. For this reason wind-mills are very objectionable, as no dependence can be placed upon them for fulfilling their allotted task in the required season. In many wind-mills levers are provided, to which mules or oxen can be harnessed, to work the mill when the wind fails, the machinery of the sails being then detached. But this expedient takes off the cattle from their regular field employment. A water-mill, or steam-engine, is free from these objections; and if it is sufficiently powerful, the whole produce of a plantation can be pressed, and the juice obtained ready for the boiling-house, in so short a time that the juice will be quite fresh. There are some water-mills in Jamaica, sufficiently powerful to grind as many canes in a week as will make thirty hogheads of sugar.

Plate Sugar-Mill contains two views of a sugar-mill to be worked by steam. K represents the axis of the crank of the steam-engine, and L the fly-wheel; I is a pinion, fixed upon the end of the axis K, and turning the large cog-wheel H, which is fastened upon the extremity of the horizontal axis G. The beams M, which support the pivots of the two latter wheels, are built into a wall, which may be considered as the wall of the house in which the steam-engine is placed. At the opposite end of the horizontal shaft, G, is fixed the bevelled cog-wheel F, which

gives motion to the horizontal bevelled wheel E, fixed upon the top of the axis, D, of the middle roller B. The two other rollers, A and C, are placed on each side of it, and all three are made to turn round together by a cog-wheel, S S S, at the upper end of each. The rollers are mounted in an iron frame, consisting of two horizontal frames, P P, Q Q, sustained by uprights O, O, and the openings of the frames P, Q, contain the brass bearings for the pivots of the three rollers, which brasses are adjustable by means of cross keys, and wedges driven through openings in the frames, so as to force the rollers towards each other, and retain them at a regular and invariable distance. The surfaces of the rollers are fluted, as is shewn in the figure, with grooves of a small depth. These make the rollers take a firmer hold of the canes to draw them in, and also facilitate the running down of the juice from the canes into a pan or cistern, which is formed round them at the lower part Q Q, by a plate of iron upon the frame Q, turned up all round at the sides; and at one end there is a spout, Q, to carry off the juice into a pipe, which leads to the boiling-house. This receptacle for the juice forms a small circular channel or gutter round the lower edge of each roller, to receive the juice which runs down the surface of the rollers; but a small raised rim is carried round the centre part or pivot of each roller, the edge of which is higher than the surface of the liquor in the pan, to prevent the juice flowing down into the bearings of the lower pivots. The weight of each roller, which is considerable, is supported in a brass step or bearing beneath the frame Q Q, as is shewn by the dotted lines in *fig. 1*; and in some cases friction-rollers are applied beneath. The rollers are made of cast-iron, and hollow within; the external surfaces are truly turned.

The operation of the sugar-mill is extremely simple: the canes are made to pass twice under the pressure, first between the rollers B, C, and then between B and A. For this purpose, the negro who attends and feeds the machine, takes the canes in a handful, and applying their ends between the rollers B and C, the motion will draw the canes in between them, and they thus receive a first pressure. Another person, who stands behind the mill, and is called the returner, bends the ends of the canes as they come through, and holds them in contact with the surface of the centre roller B, so that it will carry them round by its motion, and introduce them again between the rollers A, B, where they will come out again in front, pressed dry from their juices. The second pair of rollers, A, B, are adjusted by the wedges of their bearings, so as to be rather nearer together than the first pair, because the canes are flattened and crushed by the first pressure between the rollers B, C, and require a still greater degree of pressure the second time. The space between the rollers is very small in either case, for the canes are of a very soft substance, and they are squeezed excessively hard in passing between them. In the most complete mills they employ what is called a dumb returner, instead of having a person behind the mill to return the canes. This is a circular piece of frame-work, or kind of screen, which is fixed fast to the frames P and Q, and is made to encompass the middle roller at the back. It receives the canes as they come through the first time, and holds them in contact with the middle roller, till the ends return between the other pair of rollers. It effects this much more completely than the most attentive returner can do. The canes which have passed through the mill are squeezed completely dry, and are sometimes even reduced to powder. This refuse is called cane-trash, and is used as fuel in the boiling-house.

Sugar-mills were formerly made of wood in the framing, and the rollers were made of hard wood; afterwards they were covered with an iron casing. The best mills are now made wholly of iron, which is a better material, because it will not suffer the rollers to yield, and the canes which are presented cannot escape the full force of the pressure to which it is intended to subject them. When the sugar-mill is turned by cattle, the axis, D, of the middle roller has a long lever fixed across it, in place of the wheel E: the arms of the lever extend on each side at least eighteen feet from the centre, for the cattle to draw from; and to render the arms firm, the axis L is carried up to a considerable height above E, and oblique braces of wood are extended from the extremities of each of the arms, by which the horses or mules draw, to the top of the vertical axis, thus forming a triangle. Two mules are harnessed to each arm for the common small mills; but for a mill such as is represented in the drawing, four arms must be provided, to admit of six or eight mules to turn it.

Some sugar-mills have been made within these few years of an improved structure: the rollers are placed horizontally, and the centres of the three are arranged in a triangle, two rollers being below and one above them, so that the upper roller, to which the power is applied, touches the other two: in fact it rests upon them, and the returner is rendered unnecessary, because the two lower rollers are so near together, that the canes pass from one to the other. This is not a new invention, as we find a drawing of it in Mr. Smeaton's MS. papers entitled "sugar-mill, designed for Mr. Grey in 1754, and sent by him to Jamaica, but not then executed." This mill, which is on a large scale, and has two sets of rollers, is worked by an over-shot water-wheel, the axis of which forms the upper of the three rollers at each end, and is for that purpose cased with a cylinder of iron: the other two rollers at each end of the wheel are placed beneath the axis, so that it will rest upon them. The upper roller, therefore, answers to the middle roller of the common sugar-mill, and the two lower ones to the outside rollers; but the centres being arranged in a triangle, instead of a straight line, the two outside rollers are brought as near together as they can be not to touch, which must not be, because their surfaces move in opposite directions. The two lower rollers are contained in a small cistern, which is to receive the juice; and if the level of the water-wheel renders this cistern too low for the juice to run off to the boiling-house, a small pump is applied to lift it into a proper trough. This pump is worked by a lever and a pin, projecting from the shaft of the water-wheel. The two lower rollers are turned round by means of a cog-wheel upon the end of each, working in cog-wheels upon the axis of the water-wheel and upper roller; but it is necessary to have two separate cog-wheels upon this axis, because as the two lower rollers are placed so near together, the cogs of their wheels would touch; and as this cannot be, because the adjacent surfaces of the two lower rollers must move in contrary directions, the cog-wheels upon the two lower rollers are therefore placed in different planes, so that they will fall side by side, and will not meet each other. The teeth of the cog-wheel upon the upper roller or axis of the water-wheel is made of double breadth, or has two separate rings of cogs, one giving motion to each of the rollers. By this means the three rollers are all turned round in the same direction, as in the common vertical mill. This occasions the two adjacent sides of the two lower rollers to move in contrary directions.

The advantages of placing the rollers horizontal are considerable. The weight of the water-wheel, as well as its

power of rotation, tend to keep down the upper roller upon its work. The feeding of the mill is rendered much more regular and easy, and the canes are returned through a second pressure, without the aid of the returner.

For the convenience of feeding the mill, a board or bench is placed in a sloping direction, leading to the space between the first of the lower rollers and the upper roller: upon this bench the canes are spread in a regular and even layer, which is pushed forwards, and enters between the rollers, in the same manner as a threshing-mill is supplied. The canes as they pass through are pressed against the surface of the back lower roller, because the space between the two is not sufficient for the canes to fall through; and the motion of the back roller raises up the canes, and introduces them between the back roller and the upper roller. This second pressure deprives the canes of all their juices, and they are received on an inclined board, which slopes from the rollers sufficiently to carry down the cane-trash into a heap, from which it can occasionally be carried away. A mill of this kind will do much more work than a vertical mill, for the negro must lose time in feeding the canes between the vertical rolls, because he can only present as many as he can hold between his hands; but with a horizontal feeding board he spreads out a sufficient quantity of canes, and by pushing them forwards, presents them to the mill as fast as it will take them in, and that at the same time without choking, because he can arrange them in a layer. There is no advantage in placing the rollers vertically, which was originally done only with a view of making the most convenient application of the power of the cattle. When a water-wheel is used, or a steam-engine, the horizontal rolls are the most convenient as well as the most effective. When a water-wheel is applied to turn the common sugar-mill, the wheel E, at the top of the axis of the middle roller, is made twice or three times as large as represented in the figure, and its teeth downwards; then a wheel, similar to the wheel F, gives it motion: this latter wheel is fixed upon the end of the axis of the water-wheel, but it is then placed beneath the wheel E, instead of above it.

SUGAR, in *Agriculture*, is a material that is found to be present in many substances which are employed as the food of domestic animals, and upon which their power of nourishing and rendering them fat, in a great measure, depends. It is ascertained to exist, in a pretty large proportion, in a great number of plants and substances that are used in this way; and its feeding or fattening properties in such cases have lately been put to the test and more fully proved, in consequence of the markets of this country having been so much overstocked with this substance in its prepared state, from our possessions in the West Indies. Various hints, proposals, and attempts, for bringing it into use in this intention, have been made; and different limited trials have fully decided that it is capable of being employed for this purpose with success; but hitherto the want of proper regulations in regard to the duties that have been laid upon it in this country, have put a bar to any considerable trials or undertakings in this way. Most sorts of the above description of animals are fond of this substance, as well as the other matters which contain it; and it is found to support and keep them in condition in an equal manner to most kinds of grain, or other matter of that kind; but from the smallness of the quantity employed, some sort of distending material is constantly necessary, such as hay, cut straw, chaff, or some other similar bulky substance, in order to fill and distend the stomach in a proper manner. See *SACCHARINE Matter*.

It is observed on the same authority, that besides the

crystallized and solid sugars, there appears to be a sugar which cannot be separated from water, and which exists only in a fluid form; and that it is this which constitutes a principal part of melleles or treacle, which has also been employed with success in fattening animals of the cattle kinds, in mixture with some sort of distending substances. See *STALL-Feeding*, and *TREACLE*.

SUGAR, in *Chemistry* and *Medicine*, denotes a crystallizable essential salt, of a sweet agreeable taste, contained more or less plentifully in many kinds of vegetables, as well as in the sugar-cane, which furnishes the greatest quantity of it.

Sugar, according to the experimental trials of some, contains carbon, oxygen, and hydrogen, nearly in the proportions of three of the first, four of the second, and eight of the last. And the estimates of others give the same elementary parts, as in substances of the gum kind; as eleven of carbon, ten of oxygen, and twenty of hydrogen.

M. Marggraf has obtained sugar from the roots of several plants, as from carrots, parsnips, white and red beets. Among all the vegetables indigenous to the middle and north of Europe, which are sensibly saccharine, the beet-root is found to exceed them all in the quantity of sugar which it contains: this was ascertained by M. Marggraf, in his experiments for discovering some native sugar that might serve as a substitute for foreign sugar. (Mem. de l'Acad. de Berlin, for 1747.) See *BETA*. Two methods were pursued by this accurate chemist. One was to dry a given portion of the vegetable, to boil it in rectified alcohol, and then keep the alcoholic solution at rest for a time, by which the sugar will separate in crystalline grains. This mode, however, is much too expensive to be pursued in manufacture, but it serves as an useful indication of the comparative proportions of sugar in different vegetables, though the actual quantity obtainable by the usual mode of manufacture appears to fall far short of what is yielded by treatment with alcohol.

The other method was to imitate in the small way the process performed on the sugar-cane juice, which also was attended with a certain degree of success. The experiments of this celebrated chemist are the following: three roots were selected, the white beet, the red beet, and the skirret, all of which gave evident indications of abounding in sugar, for when cut in slices, and dried, their taste is very sweet, and the microscope shews a number of crystalline grains of sugar dispersed through their substance.

Some slices of white beet thoroughly dried, but not burnt, were powdered coarsely, and 8 oz. of this powder, again dried, were put into a bottle with 16 oz. of highly rectified alcohol, and being loosely stopped, the liquor was slowly brought to boil on a sand-bath, with frequent shaking. The vessel was then removed, the solution filtered, and the powder pressed strongly, to squeeze out all the liquor. This clear solution was then put into a bottle which was corked, and set by in a cool place. A crystallized salt deposited gradually in the course of some weeks, which was hard and tolerably pure sugar. This was redissolved and again crystallized in the same way, by which a very pure sugar was obtained. In this way, 8 oz. of the white beet-root gave half an ounce, or $\frac{1}{4}$ of sugar; 8 oz. of skirret-root, equally dried, gave 3 drachms, or about $\frac{1}{4}$ of sugar; and the same quantity of the red beet gave only 2½ drachms, or about $\frac{1}{8}$ of sugar. The solution, however, still contained a quantity of sugar mixed with the resinous part of the root, and if it is evaporated to dryness, a sweetish uncrystallized extract remains.

The skirret-root was then treated in the following man-

ner without alcohol, with a view of extracting the sugar. A quantity of it was chopped small, bruised in a mortar, and the juice expressed through a cloth bag, and the pulp was again moistened with water, and expressed, to get out all the saccharine liquor. The whole liquor was then kept at rest for 48 hours, in a cool cellar, by which most of the feculence subsided, and the clear liquor was carefully drawn off. The author lays much stress on this part of the process, which, if it is not done properly, considerably hinders the subsequent production of the sugar. The clear liquor was then heated in a copper pan, clarified with white of egg, and boiled down to the consistence of thick syrup, and kept in this state for about six months in a warm place, by which it concreted into a semi-fluid crystalline mass, composed of impure crystals of sugar and a good deal of syrup. The whole mass was then a little warmed, to give the syrup a little more fluidity, and poured into a funnel-shaped vessel of tinned iron, with holes at the sides and bottom, and set by in a warm place; by which, after a considerable time, the impure uncongealable syrup slowly filtered to the bottom, leaving the purer saccharine part in the form of a brown granular mass. The latter was then re-dissolved in water, again clarified with white of egg, strained, boiled with a little lime, again strained, and then evaporated to a thick consistence, and stirred till cold. A sugary viscid mass still purer than the last was thus obtained, which, on being kept for a week in a funnel-shaped pot, with a single hole at bottom, plugged up, congealed into a grained sugar equal to good muscovado, from which a syrup separated and dropped through when the plug was withdrawn.

Such is the process of this chemist to obtain a sugar from the skirret-root, and he proceeded in the same manner with the white and red beet-root, and with the same success. He further observes, that he rasped the beet-roots, being harder than the skirret; that the mucilaginous deposit from the beets was browner and less copious than from the skirret; the sugar from the white beet was the most abundant and the purest, and that from the red beet was the least so. The mucilage or sediment from the skirret, washed with cold water and purified, yielded a very good white farina.

All these roots are very watery. The white beet loses by gentle, but entire, desiccation, full three-quarters of its weight, and the red beet seven-eighths.

For an account of the experiments of Achard, and other chemists, see *BETA*.

It is also presumed, that much sugar may be obtained from other vegetables, as from green peas, cabbage, green farinaceous grains, as barley, (see *MALT*), ripe fruit of grape, date, and fig, and the root of parsnip, &c. and from several trees, as the sycamore and birch trees. Green maize (see *MAIZE*) contains a liquor from which the American savages are said to extract sugar. It may also be extracted from the *asclepias caule erecto simplici annuo*, and from any flowers collected while the morning dew is upon them. But the vegetable which yields the largest quantity of sugar, next to the sugar-cane, is the sugar-maple. (See *MAPLE*.) The methods employed for extracting sugar from this tree in Canada are related by M. Gautier, in the Mem. des Scav. Estrang. tom. ii. and by M. Kalm, in the Swedish Mem. for 1757. (See *MAPLE Sugar*.) The season for tapping the tree is from February to April, for about six weeks, during which time a tree of moderate size will yield from 20 to 30 gallons of sap, from which may be made about five or six pounds of pretty good sugar. The tree does not seem to sustain any injury from this operation, for the juice is more saccharine from the trees that have

been already tapped, than from those that are fresh. This juice, which is clear, and of a pleasant taste, is made into sugar by the farmers in the country, with a simple apparatus. It is usually clarified with lime and white of egg (or milk) boiled down, grained, and clayed, like the cane-juce. Sometimes the quantity of liquid is reduced by freezing at the proper season, which is preferred to evaporation. This substance might, it is supposed, be made into loaf-sugar, as well as the mucovado; and it is commonly used in a half-purified state, like the common moist sugar. The juice will also furnish a pleasant wine by fermentation, and a good vinegar.

By discovering a menstruum that would dissolve the sugar, and not the slimy substance, the saccharine and mucilaginous parts of plants might be separated from one another with advantage. Sugar is scarcely, if at all, contained in any part of the animal kingdom, (honey certainly belonging to the vegetable,) except in milk, and in the urine, during the singular disease called "diabetes mellitus."

Pure sugar appears either in a regularly crystallized form, or in shining white crystallized grains. Both in candy and loaf it is hard and brittle, inodorous and sweet. If hard loaf-sugar be rubbed in the dark, it is very luminous. With the nitric acid it is convertible chiefly into the oxalic acid. It is very soluble both in water and alcohol. Melasses, which are constituted chiefly of the uncrystallizable parts of the juice of the sugar-cane, and which Proust has denominated liquid sugar, are more soluble in alcohol than sugar. Sugar requires only its own weight of water at 48° for its solution; and when united at a higher temperature with a smaller quantity, it remains dissolved and forms a syrup. The watery solution, mixed with mucilaginous, farinaceous, or other matters, readily enters into the vinous fermentation; whence it is inferred, by considering that the strength of the liquor and quantity of alcohol produced depend on the quantity of sugar, that the most essential part of the process of vinous fermentation is the conversion of sugar into alcohol. Four parts of boiling alcohol dissolve one part of sugar; but a moiety of sugar again separates by rest in crystals. Oils readily combine with sugar, and the mixture is miscible with water. Lime and the fixed alkalies unite with sugar, and form compounds, without any sweet taste. The concentrated strong acids dissolve and decompose sugar, but the weaker simply dissolve it; and the alkaline and earthy hydro-sulphurets, sulphurets, and phosphurets, decompose it, and resolve it into a substance resembling gum. Its ultimate constituent parts, according to Lavoisier, are 64 of oxygen, 28 of carbon, and 8 of hydrogen, in 100 parts.

Sugar melts at a heat considerably above that of boiling water, and forms a blood-red viscid fluid, which, cooled, has a flavour of empyreuma, not ungrateful, mixed with the natural sweetness. When melted, it takes fire from a lighted substance, and burns with a strong red flame, and a penetrating odour, which excites coughing, and is owing to the production of an acid.

If sugar be distilled *per se* from a glass retort with a heat gradually increased to redness, and the products be carefully collected, they will be found to be, first, a coloured liquor, strongly acid and pungent, called the "pyromucous." A large quantity of gas comes over at the same time, which is hydro-carbonat mixed with a little carbonic acid; and a very pure charcoal is left behind, which burns away in the open air without leaving any residue. Neither azot, ammonia, nor lime, nor any other substance, is obtained in this process, whence it appears that sugar is one of the purest hydro-carbonous oxyds known.

The actual chemical differences between mucilage and sugar, as stated by Mr. Cruikshank, are the following: sugar is soluble both in water and alcohol, and crystallizable from either solution; but mucilage is insoluble in alcohol, and refuses to crystallize from its watery solution: 480 grains of sugar yielded by distillation 120 grains of charcoal, 270 grains of liquid pyromucous acid, 41 ounce-measures of carbonic acid gas, and 119 ounce-measures of hydro-carbonat gas:—the same quantity of gum arabic yielded 96 grains of charcoal, 210 grains of pyromucous acid, 93 measures of carbonic acid, and 180 of hydro-carbonat. It also gave about 10 grains of lime, and the acid, when saturated with lime, gave out a little ammonia; and hence it appears, that lime and azot are substances that belong to mucilage, and not to sugar. The habitudes of each substance with nitric acid differ also considerably. When gum arabic (*e. g.*) is heated with nitrous acid only till nitrous gas begins to be disengaged, a quantity of white insoluble matter precipitates, which is the "mucous" acid, and the residue is "malic" acid, which a farther addition of the nitric converts into oxalic. But sugar is changed into oxalic, or malic and oxalic acid, without the production of any mucous acid. The quantity of oxalic acid produced from a given weight of sugar with nitric acid also exceeds that yielded by the same weight of mucilage with the same proportion of acid. In the spontaneous changes, also, sugar and mucilage differ essentially: sugar being the essential material of the vinous fermentation; but mucilage is incapable of this process when pure, and appears to contribute little to the generation of alcohol, when in combination with fermenting materials.

From the known properties of sugar, it is supposed to unite the unctuous part of the food with the animal juices: hence some have concluded, that it is nutritive to animals, and increases corpulence; others have ascribed to it a contrary effect, as it is said to prevent the separation of the oily matter, which forms fat, from the blood; and others, again, have charged it with rendering the juices thicker and more sluggish, retarding circulation, obstructing the natural secretions, and thus occasioning or aggravating scorbutic, cathartic, hypochondriacal, and other disorders. However, experience seems to shew, that the moderate use of it is at least innocent.

Professor Murray, who has treated this subject very elaborately, thinks that by the fermentation which sugar undergoes in the stomach, and by its relaxing resolvent saponaceous qualities, as well as by the acid which it contains, it rather tends to emaciate than to fatten the body; and in this opinion he observes that he has the authority of Boerhaave, who says, if this sweet be taken in large quantities it produces emaciation, by dissolving too much of the animal oil. He is therefore much surprised, that Mr. John Hunter should lately recommend sugar and honey as the best restoratives to those suffering from great debility by a long course of mercury. What may be the effects of sugar in this respect in its refined state may be difficult to determine; but in its crude state there can be no doubt of its affording a considerable share of nourishment, both as combined in various vegetable matters, and as separated by art. Those animals which wholly feed upon it in the sugar islands, become remarkably corpulent; and the negro children, whose diet happens sometimes for a season to be confined to melasses, are easily distinguished from others by their superior bulk; they are, however, more disposed to suffer by worms, and are likewise less active and healthy.

Sugar however appears, by the experiments of several writers, to prove deleterious to various kinds of worms,

either by immersing them in a solution of sugar, or sprinkling it upon their bodies; and twenty grains of lump-sugar forced into the stomach of a frog, produced immediate torpor and death, which followed in the course of an hour: it also proved fatal to pigeons, and to the gallinæ kind, but not to sparrows; and with sheep and dogs it had no other effect than that of a cathartic.

Sugar may certainly be taken into the stomach in pretty large quantities, without producing any bad consequences; though proofs are not wanting of its mischievous effects, in which, by its attenuating and dissolving the fluids, and relaxing the solids, debility and disease are said to have been produced. Stark for many days took from four ounces of sugar, to eight, ten, sixteen, and even twenty, with bread and water, by which nausea, flatulency, ulceration in the mouth, with redness and tumefaction of the gums, oppression, purging, pain, and redness of the right nostril, bleeding at the nose, and livid streaks over the right scapula, were produced. We are also told that a boy, who was much affected by acidity of the stomach, in a short time greedily ate a large quantity of lump-sugar; soon afterwards he was taken ill, and the next morning found dead in his bed. Upon examining his body, red spots, and other marks of a dissolved state of the blood, were discovered. What degree of credit ought to be given to these and other cases of the like kind, we leave to the judgment of our readers: but that the liberal use of sugar to many stomachs has greatly

impaired the digestive powers, and laid a foundation for various complaints, is highly probable. At the same time we must admit, that several indulge largely in this article, if not with advantage, at least with impunity.

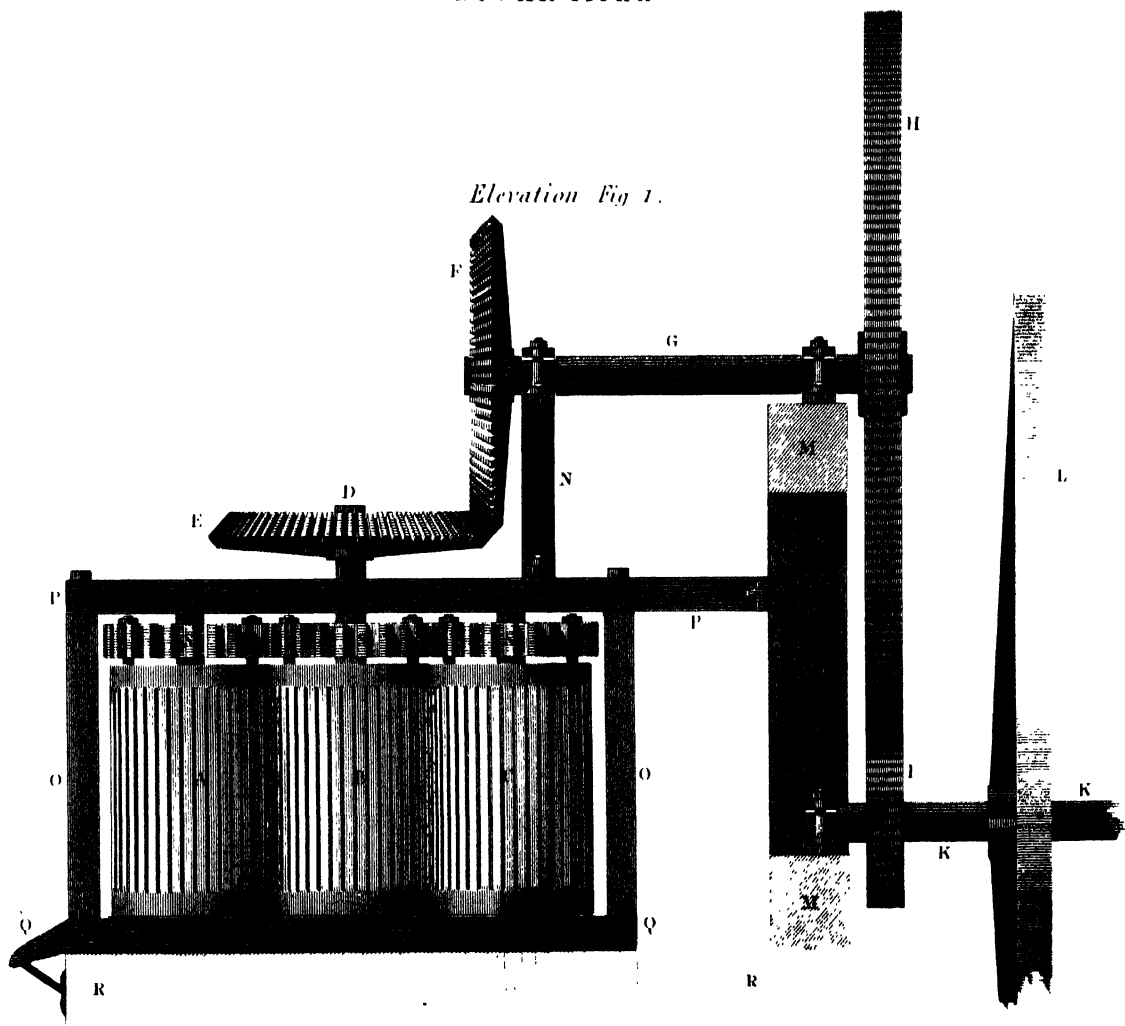
As a medicine, sugar cannot be considered to possess much power. Dr. Cullen classes it with the *attenuantia*; and Bergius states it to be *saponacea*, *edulcorans*, *relaxans*, *pectoralis*, *vulneraria*, *antiseptica*, *nutriens*. In catarrhal affections, both sugar and honey are frequently employed: it has also been advantageously used in calculous complaints; and from its known power in preserving animal and vegetable substances from putrefaction, it has been given with a view to its antiseptic effects. The candy, by dissolving slowly in the mouth, is well suited to relieve tickling coughs and hoarseness. The use of sugar in various medicinal compositions is too obvious to require being particularly pointed out.

Raw sugar and melasses, by virtue of their oily or treacly matter, prove emollient and gently laxative. The crystals or candy are most difficult of solution, and hence are most proper where this soft lubricating sweet is wanted to dissolve slowly in the mouth, as in tickling coughs and hoarseness. Refined sugar, externally applied, is escharotic.

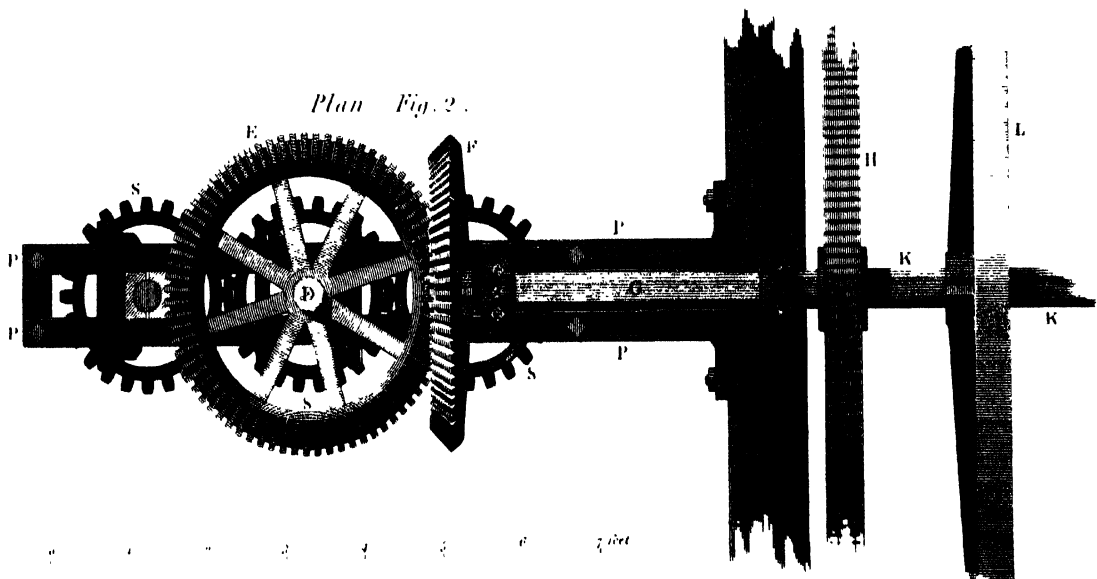
Coarse sugar, in which there is more oil than in refined sugar, is recommended as a good medicine in collyria for discharging ulcers of the cornea, in which astringents are hurtful. Aikin. Lewis. Woodville.

SUGAR MILL

Elevation Fig. 1.



Plan Fig. 2.



Sulphuric Acid

SULPHURIC ACID, *Vitriolic Acid*, or *Oil of Vitriol*, is formed by oxygen and sulphur; but it is also found that water is essential to the existence of this acid.

In the most concentrated state in which sulphuric acid can exist, it is a transparent, colourless, dense liquid, of an oily consistence, and greasy to the touch. Its taste is very caustic, and so extremely sour, that a few drops only will render a pint of water too sour to drink. It has no smell, except when it is contaminated with animal or vegetable matter, the smallest quantity of which discolours it. When dropped on these substances it destroys their texture, and leaves a black mark. It changes most vegetable blues to red, and manifests other qualities of acids in a very eminent degree.

The fixity of sulphuric acid is very considerable: when in the state of common oil of vitriol, it requires nearly a red heat for its vaporization; and though when diluted with water it will boil at a considerable lower temperature, yet little else than water is driven off, and the acid becoming more and more concentrated, requires a continually increasing heat to keep up its ebullition, till it arrives at the degree necessary for the volatilization of the acid itself.

Sulphuric acid freezes or crystallizes by exposure to cold, and it appears to congeal with more ease when moderately concentrated than when it is diluted: this remarkable circumstance was first pointed out by the duc d'Ayen, was then confirmed by Morveau, and has since been treated at large, and in a very satisfactory manner, by Mr. Keir. (*Phil. Trans.* for 1787, p. 267.) This accurate observer found that sulphuric acid of the specific gravity of 1.78, congeals at about 40° Fahr.; but that if the density is either increased or diminished, a greater cold is required for its congelation. Proceeding from the above density in each direction, he found that sulphuric acid at the specific gravities of 1.786 and 1.775, or at any intermediate density, freezes when exposed to the cold of melting

snow; that if the energy of the freezing mixture be increased by the addition of common salt, it will congeal sulphuric acid at the specific gravities of 1.841 and 1.75, or at any intermediate density; but that acids at the specific gravities of 1.815 on the one hand, and 1.745 on the other, continue fluid. Sulphuric acid while freezing contracts considerably in its dimensions; sometimes it forms a confused mass, but often shoots into large regular crystals in the form of oblique truncated octohedrons, or compressed hexahedral prisms, terminated by hexahedral pyramids.

Sulphuric acid attracts water with great avidity, and accumulates in bulk. This takes place even in a stopped bottle, if the stopper does not fit very tight.

If some of the sulphuric acid at the usual density of 1.845 be mixed with one-fourth of its weight of water, the temperature of the mass instantly rises to near 300° Fahr. and a mutual penetration takes place, the density of the compound being greater than the mean density of its ingredients. If even four parts of sulphuric acid and one of ice, both at the temperature of 32°, be mixed together, the heat of the mass will rise to 212°; but if the proportion of ice be increased considerably, the caloric necessary to the liquid state of the mixture will exceed that which is extricated during the combination of the ingredients, and cold will be produced; thus, if four parts of ice and one of acid at 32° be mixed together, the temperature of the mass will be cooled down to - 4°. But in all cases where concentrated sulphuric acid is employed in the composition of freezing mixtures, there is at the moment of their combination, as Beaumé has well observed, a very sensible production of heat, which must materially diminish the frigorific effect; thus, according to the able chemist last mentioned, (*Chem. Exper.* i. p. 219.) if one part of sulphuric acid at the common temperature, and four parts of ice, be mixed together, the first effect is to raise the thermometer in

an infant to 94° Fahr., from which it sinks as speedily to 32° . But if the acid has been previously diluted with water, the temperature sinks on the addition of ice to 5° Fahr. without any previous heat having been excited. So powerful is the affinity of sulphuric acid for water, that it will absorb moisture with great rapidity from the air, so as in a very few days to double or treble its weight. Even a boiling temperature, when the acid is moderately concentrated, will not counterbalance this strong tendency; hence it is that sulphuric acid cannot by boiling in an open vessel, be concentrated nearly so much as by distillation in a close apparatus.

The specific gravity of this acid varies from 1.85 to the most dilute acid, depending upon the water it contains.

The following table of the specific gravities of sulphuric acid of different strengths, is taken from Mr. Dalton's New System of Chemical Philosophy.

TABLE of the Quantities of real Acid, in 100 Parts of Sulphuric Acid at 60° .

Atoms of Acid Water.	Acid per cwt. by		Specific Gravity.	Boiling Point.
	Weight.	Measure.		
1 + 0	100	Unknown.	Unknown.	Unknown.
1 + 1	81	150	1.856	620°
	80	148	1.849	605
	79	146	1.848	590
	78	144	1.847	575
	77	142	1.845	560
	76	140	1.842	545
	75	138	1.838	530
	74	135	1.833	515
	73	133	1.827	501
	72	131	1.819	487
	71	129	1.810	473
	70	126	1.801	460
	69	124	1.791	447
1 + 2	68	121	1.780	435
	67	118	1.769	422
	66	116	1.757	410
	65	113	1.744	400
	64	111	1.730	391
	63	108	1.715	382
	62	105	1.699	374
	61	103	1.684	367
	60	100	1.670	360
1 + 3	58.6	97	1.650	350
	50	76	1.520	290
	40	56	1.408	260
1 + 10	30	39	1.300	240
1 + 17	20	24	1.200	224
1 + 38	10	11	1.100	218

The acid at 100, at the head of the column, is the real acid, or that which combines with different bases, to form the salts called sulphates. It is difficult to say whether it does really exist in a separate state. Mr. Dalton says it is formed when nitrous gas, oxygen, and sulphurous acid, are mixed together, and appears in shining crystals, like hoar frost. On the other hand, sir Humphrey Davy asserts, that when nitrous acid gas, and sulphurous acid gas, are mixed in a glass globe, and the gases perfectly free from moisture, no sulphuric acid is formed. But if a drop of water be introduced, there will be an immediate condensation, and

a beautiful white crystalline solid will line the interior of the vessel: whereas, if the globe contain plenty of water, nitrous gas will be given off with great violence, and the water will be found to be a solution of oil of vitriol. We should feel some delicacy in doubting the accuracy of either of these authorities, but it is nevertheless certain, that one of them has been deceived. The experiments were certainly a little different. Mr. Dalton employed nitrous gas and oxygen, which we should imagine could not give a result different from sir Humphrey's, who employed the nitrous acid ready formed. Both these chemists seem to agree, that the acid of the specific gravity 1.85 contains an atom of water. This acid is the strongest that can be made by concentration, for at its boiling point, which is 620° , the acid and water rise together.

It will be perceived from the table, that the specific gravity varies very little with the first portions of water; and hence it is a very uncertain test of the value of very strong acids. We have generally observed, that those who keep an hydrometer for the purpose of assaying the oil of vitriol, hardly ever complain of its want of specific weight.

Mr. Dalton recommends the boiling point of strong acids as a better test of their strength. The table shews, that when the quantity of real acid varies *one per cent.* the specific gravity is only changed in the third decimal place; but the boiling point varies as much as 15° . This points out a simple method of assaying sulphuric acid with much greater precision than by the hydrometer. An instrument might easily be constructed for this purpose. It should consist of a small platina cup, capable of holding as much sulphuric acid as will cover the bulb of a mercurial thermometer. An upper part may be attached to this cup, to contain the stem of the thermometer, and at the same time to guard it from the heat of the fire on which the cup is placed.

The cup of platina, being filled with the acid to be tried, may be placed on a small charcoal fire, or a sand-bath, or indeed a clear common fire, till the acid boils, when it will shew the strength of the acid, by degrees marked upon the scale of platina; the degrees being expressions of the specific gravity, instead of degrees of temperature. The first column in the table gives the relative number of atoms of water and acid for different strengths. The way in which the acid mixes with water as well as with the solutions of salts, seems to favour the idea of their proportions being indefinite. But this is merely an apparent anomaly. The acid may combine with one, with two, with three, and perhaps a greater number of atoms of water, but this number may still be limited. An acid weaker than the limited number of atoms of water would give, is constituted by the limited compound becoming equally dispersed through a mass of water, the excess of water not being combined but merely mixed. Such may also be the case with solutions of salts.

That the acid and the water are combined chemically, the condensation of volume, and change of temperature, clearly prove; and in the perfect state of chemistry, it is not less clear that the proportions of compounds are limited.

Sulphuric acid is constituted by one atom of sulphur 15, and three atoms of oxygen 22.5, making its atom 37.5. The strongest liquid acid, as will be seen by the table, will consist of an atom each of acid and water, which will be $37.5 + 8.5 = 46$: the specific gravity of this is 1.85. Acids of this strength, down to 1.8, have the name of oil of vitriol, from the circumstance of this acid being formerly distilled from green vitriol. That the component parts of sulphuric acid are sulphur and oxygen, may be demonstrated either by analysis or synthesis; thus, if sulphur be

digested with nitric acid, nitrous gas will be given out from the decomposition of the acid, while the oxygen, the other element, will combine with the sulphur, and form with it sulphuric acid; on the other hand, if sulphate of soda be mixed with charcoal and exposed to a red heat, the sulphuric acid is deoxygenated by the superior affinity of the charcoal; carbonic acid and carbonous oxyd are produced, and the sulphate of soda is found to be converted into sulphuret of soda, from which the sulphur may readily be procured by solution in water, and the addition of an acid.

But though the elements of sulphuric acid are ascertained, much doubt still exists with regard to their relative proportion.

Several methods have been employed for ascertaining these proportions. Lavoisier, for this purpose, placed a given weight of purified sulphur in a receiver, with a little water to absorb the acid produced; then setting fire to the sulphur, he supplied it with oxygen gas of known purity, till the combustion ceased: then by ascertaining the weight of sulphur burnt, and of oxygen gas consumed, he inferred that sulphuric acid was composed of 71 parts of sulphur to 29 parts of oxygen. Berthollet, having ascertained that nitre and sulphur, in the proportion of four parts of the former to one of the latter, when heated in a retort, reacted on each other quietly and without explosion, mixed together 288 grains of nitre, and 72 grains of sulphur, and heated the mixture in a glass retort till the emission of nitrous gas entirely ceased. During the process, 12 grains of sulphur had sublimed unaltered, and 228 grains of sulphate of potash were produced by the combination of the alkaline base of the decomposed nitre with the newly produced sulphuric acid. Now, according to Kirwan, sulphate of potash is composed of 45.2 sulphuric acid, and 54.8 potash; therefore, out of the 228 grains of sulphate of potash, 103 grains were sulphuric acid, composed of $72 - 12 = 60$ grains of sulphur, and 43 grains of oxygen: hence 100 parts of sulphuric acid consist of

Sulphur	-	-	-	58.2
Oxygen	-	-	-	41.8
				100.0

Another method, followed by Berthollet, Thenard, and Chenevix, and which some have thought to be upon the whole the best, is to digest a given weight of sulphur in nitric acid, till it is completely dissolved and acidified, (which, if performed with care, may be effected without the production of any sulphurous acid,) then to add a solution of nitrate or muriate of barytes as long as any precipitate takes place, by which the whole of the newly-formed sulphuric acid will combine with barytes into an insoluble salt; then to edulcorate and ignite the sulphated barytes, and from its weight to deduct that of the barytic base; the remainder consequently will indicate the amount of sulphuric acid produced, from which, by subtracting the known weight of sulphur, we get by inference that of the oxygen.

By compounding the results arising from the experiments of several skilful chemists, the composition of sulphuric acid seems to be, according to

		Klaproth.	Thenard.	Chenevix.
Sulphur	-	24.3	37.4	41.2
Oxygen	-	75.7	62.6	58.8
		100	100	100

By another Statement.

		Klaproth.	Thenard.	Chenevix
Sulphur	-	43.2	57.4	61.5
Oxygen	-	56.8	42.6	38.5
		100	100	100

By a third Statement.

Sulphur	-	41.8	55.56	59.1
Oxygen	-	58.2	44.44	40.9
		100	100	100

Muriatic acid gas combines readily, and in abundance, with sulphuric acid; and the compound acquires a brownish tinge, and, when exposed to the air, emits dense white fumes of muriatic acid gas, probably mixed with a little sulphuric acid, as their odour is more pungent and suffocating than that of simple muriatic acid. The nitric and sulphuric acids unite readily together, either by direct mixture, or by adding a little nitre to sulphuric acid. This compound is of considerable use for recovering the silver from clippings and other refuse of the manufactories of silver-plate. Sulphuric acid absorbs, by agitation, a considerable quantity of red nitrous vapour, and in consequence acquires a light blue colour. The mixture, when exposed to the air, gives out a white vapour. If water is added, the great heat that is thereby generated causes a very rapid and copious emission of the nitrous vapour, and sulphuric acid and water alone remain behind. Sulphuric acid, thus impregnated with nitrous vapour, after a time becomes nearly colourless, and then concretes into solid crystals. In this state, when dropped into water, it acquires a green colour, and both the crystals and water sparkle with the spontaneous and copious production of nitrous gas. When the crystals are simply exposed to heat, they melt, emit a dense red fume, and, after the nitrous vapour is thus driven off, the residue is common sulphuric acid.

Concentrated sulphuric acid, even when cold, acts in a very striking manner on most kinds of vegetable and animal matter. If a piece of paper or straw, for example, be immersed in sulphuric acid, the texture of the straw is speedily broken down, it acquires a deep black colour, and is diffused through the acid in a state of half solution. This phenomenon, however, does not take place, as is generally supposed, on account of the re-action of the sulphuric acid on the carbon and hydrogen, producing sulphurous acid, but from the strong affinity of the acid for water; in consequence of which, the oxygen and hydrogen of the vegetable matter combine together into water, while the carbon is precipitated.

Sulphuric acid combines with all the metallic oxyds, with the alkalies, and all the earths except silica, forming an important genus of salts, called in the reformed nomenclature *sulphates*; which see.

The following is the order of the affinities of sulphuric acid: barytes, strontian, potash, soda, lime, magnesia, ammonia, glycine, yttria, alumina, zircon, metallic oxyds.

When sulphur is burnt in oxygen, whether in the pure gas or in the atmosphere, it forms only sulphurous and not sulphuric acid; but if the sulphurous acid be absorbed by water, and exposed to the air for some time, the latter absorbs oxygen, and is converted into sulphuric acid. Hence sulphuric acid cannot be formed by the mere combustion of sulphur; a circumstance which renders the process of manufacture much less simple than it otherwise might be.

Sulphuric acid is at present formed by mixing together one part of nitre and seven parts of sulphur. This mixture is placed in a chamber, lined with lead. When these materials are set on fire, the nitre facilitates the burning of the sulphur by the oxygen it affords; but it does not furnish sufficient to convert the sulphur into sulphuric acid. The 7 parts of sulphur will require 10.5 of oxygen for that purpose, but the nitre employed with it can furnish no more than .225, supposing the nitric acid to be reduced to the state of nitrous gas. This is so small a portion of the whole, that some other source must be explored, which is doubtless the atmosphere.

The combustion of the sulphur, which is facilitated by the presence of the nitre, first converts the sulphur into sulphurous acid; which, from its gaseous form, would soon be dissipated, if it were not condensed by its conversion into sulphuric acid. When a portion of the nitric acid of the nitre is decomposed by the sulphur, nitrous gas is evolved; but in its ascent, it meets with the oxygen in the chamber, and is converted into nitrous acid gas, which appears in red fumes. The new-formed substance can now dispose of an atom of oxygen, which the sulphurous acid is wanting to convert it into sulphuric acid. The bottom of the leaden chamber is covered with water to the depth of two or three inches. This water seems to answer a double purpose; in first facilitating the action of the nitrous acid gas upon the sulphurous acid, and then dissolving the sulphuric acid as it is formed. When the nitrous acid gas has disposed of its atom of oxygen, it returns to the state of nitrous gas; and in rising, unites with more oxygen, which it again gives to sulphurous acid; thus continuing its receiving and giving office, till it is accidentally dissipated through the same apertures which admitted the common air. A necessary connection between the chamber and the atmosphere will appear obvious. Atmospheric air must be admitted for the combustion of the sulphur, and to afford oxygen to the nitrous gas; and through the same, or some other opening, the residual azote must be returned into the open air. Some nitrous gas, and probably nitrous acid gas, will escape at the same time. If the latter were not the case, a constant decomposition of nitre by the sulphur would not be necessary. The theory of this process has been given by the French chemists, Chemint and Desormes. Sir Humphrey Davy objects to it in some degree. He holds, that the union of the oxygen of the nitrous acid with the sulphurous acid does not take place till they come in contact with water; the latter, according to his opinion, being essential to the constitution of the sulphuric acid. If the above theory be correct, a simpler mode of manufacture might be pointed out. The combustion of the sulphur might be so managed, as to furnish the sulphurous acid without loss, but mixed with azote.

From another source nitrous gas and atmospheric air may be furnished. These with the other products meeting where water is present, ought to form sulphuric acid in a very small space compared with the large chamber at present employed. The gases, by this means, might be furnished in proportions so exact, that nothing but azote would escape.

The acid and water which cover the floor of the chamber now only arrive at a certain strength, which is very far short of that required. At that strength it is drawn off, and concentrated by evaporation. This used to be performed in glass retorts, which are very liable to break. If this is not performed in a vessel from which there is but a small opening, the acid would not part with so much of its water, and its concentration would be limited at a very inferior

strength to that used for most purposes. Dr. Wollaston has introduced vessels for the concentration of oil of vitriol made of platina: they are very expensive, but answer the purpose admirably. Some manufacturers use leaden vessels for this purpose.

Sulphuric acid is employed extensively in bleaching, with the oxymuriatic acid, and in dyeing. It is the cheapest and most useful acid for cleaning the surface of plates of silver, copper, and iron, by dissolving their oxys.

The sulphuric acid is said to have been found by Baldassari, in a concrete state, lining a grotto in mount St. Amiato, in Tuscany: it also occurs in the crevices of volcanic mountains, and dissolved in some mineral waters. But the sulphuric acid of commerce is obtained either from the distillation of sulphate of iron, or from the combustion of sulphur. We shall here subjoin a brief account of both methods, referring to Aikin's Dictionary of Mineralogy, &c. for farther particulars.

Sulphate of iron, or green vitriol, consists of sulphuric acid, water, and oxyd of iron: by proper methods, the acid may be separated from the other ingredients of the salt; and this continued to be the only origin of sulphuric acid in the great way, till the discovery, by the manufacturing English chemists, of the art of preparing it by the combustion of sulphur. As this latter discovery has not, however, as yet entirely superseded the former, we shall give an account of both, beginning with the most ancient.

Sulphuric acid is thus prepared at Bleyl, in Bohemia. A long horizontal furnace or gallery of brick-work is constructed, capable of receiving a number of retorts: the retorts themselves are pear-shaped vessels, with a slightly curved neck, by which they fit into earthen receivers nearly of the form of common retorts. The whole apparatus being prepared, each retort is charged with three pounds of sulphate of iron, previously calcined at a full red heat, and the fire is lighted. The first effect of the heat is to drive off the moisture absorbed by the vitriol in the interval between its calcination and distillation: this phlegm, being only very slightly acidulous, is allowed to escape; and when it ceases to come over, the receiver with a little water in it is luted on to the retort. The fire is now raised, and kept up brisk for 32 hours, during which time the acid rises in the form of dense white vapours, which fill the receiver, and are there absorbed by the water. These vapours being at a high temperature, soon render the receiver very hot: hence the workmen judge of the termination of the process, by the receiver becoming cool, in consequence of the vapour ceasing to rise. The red oxyd of iron, or colcothar, is now taken out of the retort, and its place is supplied with a fresh charge of calcined vitriol: the distillation then takes place as already described, except that the former produce of acid is not emptied out of the receiver, and, therefore, there is no occasion to add any water. If the retort is well made, and carefully luted all over, it will last for three successive distillations, and the quantity of acid obtained is nearly equal to half the weight of the calcined sulphate.

If the acid be examined at different periods of the distillation, it will be found to be more and more dense, according to the violence of the fire required for its extrication: the latter portion, if received in a separate vessel, will generally congeal upon cooling; hence it is called *glacial sulphuric*

This acid used to be, and perhaps is still, prepared at Nordhausen, in Saxony: it is of a dark brown colour, and exhales, when exposed to the air, abundance of dense, white, suffocating vapours; its usual specific gravity is = 1.95. For other properties, see Aikin, *ubi supra*.

From the facts which he has recited it seems probable, that the essential difference between the common and glacial acid is, that the latter, from the mode in which it is prepared, contains a smaller portion of water than the former, and that to this is owing both its volatility and property of congelation. It is incidentally mixed with sulphurous acid, but the presence or absence of this does not appear to be of any material importance.

The sulphates of copper and zinc have occasionally been employed, instead of the sulphate of iron, but with a manifest disadvantage, both because they are dearer than the latter salt, and because they require a higher and longer continued heat to drive off the whole of the acid.

The following is the usual method of manufacturing sulphuric acid from the combustion of sulphur. A chamber is constructed of frame-work, and lined with strong sheet-lead; the only aperture is a small door, made to shut very close, the bottom of which is a little higher than the floor of the chamber. Water is poured into this chamber, till it rises to the height of an inch or two upon the floor, and a stand is introduced, on which is placed an earthen pot containing a few pounds of sulphur and nitre, in the proportion of from eight to ten of the former to one of the latter. This mixture is set fire to by means of a red-hot iron, and the door is immediately closed. At the expiration of about six hours, a second charge of sulphur and nitre is introduced, which after a similar interval is replaced by a third, and so on without intermission for a fortnight or three weeks. At the end of this period, the water in the chamber is sufficiently acidulated; it is accordingly transferred to a leaden boiler, where the greater part of the water is evaporated. In proportion, however, as the acid becomes more concentrated, it is more disposed to corrode and dissolve the lead of the boiler; therefore, before this degree of concentration takes place, the liquor is transferred into large green glass retorts, where a degree of heat is applied sufficient to drive off almost the whole of the water. As the acid becomes stronger, it also becomes clearer and less coloured, in consequence of a portion of acid re-acting on the impurities with which it is tinged, and thus destroying them. When the acid is thus brought to the required density and clearness, it is poured out of the retorts into large globular glass bottles, surrounded with wicker-work stuffed with straw, called *carbays*, and is then brought into the market, under the name of *oil of vitriol*.

The sulphuric acid obtained from the distillation of green vitriol exists ready formed in the salt: its extrication is a perfectly simple process, and the only impurities that it can possibly contain are sulphurous acid, and a very minute portion of oxyd of iron, and of the earth of the retort. When loaded with sulphurous acid, it has a suffocating odour, and, when exposed to the air, gives out a white vapour like strong muriatic acid. It used formerly to be sold in this state by the name of *fuming oil of vitriol*, and was further distinguished by its property of congealing into a soft ice, at a very moderate degree of cold. By dilution with a little water, and subsequent boiling for few minutes in a glass vessel, the sulphurous acid is driven off, and the residual fluid is common sulphuric acid in a state of very considerable purity.

When the method of producing sulphuric acid by the combustion of sulphur and nitre was first discovered, the apparatus employed was a series of very large glass balloons, at the bottom of each of which was a little water to condense the vapour; only a small quantity of the mixture could be burnt at once, and constant superintendence was necessary to supply the balloons with fresh charges of the

materials. In order to save much of this manual labour, and the heavy loss arising from the frequent fracture of the vessels, leaden chambers were made use of, which, besides requiring less attendance, and being upon the whole cheaper, rendered it easier for the manufacturer to extend his establishment to any required magnitude. These chambers are of various construction: the most simple and in most general use are furnished only with two apertures, namely, a small door, by which the water and the sulphur and nitre are introduced, and a leaden pipe with a stop-cock, by which the water, when acidulated, is drawn off: other chambers have besides a few small apertures, for the introduction of atmospheric air during the combustion, and a steam-pipe connected with a boiler, it being found that if the water is introduced in the state of steam, a much more rapid condensation of the acid ensues than in the usual way of proceeding. In some of the best contrived chambers, the combustion of the nitre and sulphur is effected in a separate stove, and the acid vapour thus produced is poured by means of a pipe into the condensing chamber.

There is a good deal of difference among the manufacturers as to the proportion of nitre employed: by some it is made equal to one-fifth of the sulphur, while by others it is not allowed to exceed one-tenth. This, however, appears to be satisfactorily established, that within the above limits the greater the proportion is of nitre, the more easily condensable will the acid vapour be, and the less sulphur will be lost in the form of sulphurous acid gas. If the nitre exceeds one-fifth of the sulphur, the combustion will be so rapid as to drive into the chamber a considerable proportion of sulphur unaltered. It would conduce much to the purity of sulphuric acid, and might probably be found even to be an economical plan, to line the chamber with glass instead of sheet-lead: the general appearance of the chamber would then resemble a green-house, and all the wood-work should be faced internally with glass. A composition of wax, maltich, and fine sand, would form a strong cement for the glass, and little liable to be acted on by acid vapours, more especially if the interstices filled up with it were dulled with powdered glass, or very fine sand, while the cement was yet warm and adhesive. Such a chamber would have the additional advantage of allowing the operator to see what was passing within, without the necessity of opening the door.

The common English sulphur is unfit for the preparation of sulphuric acid, on account of a yellowish-brown colour which it gives to this fluid, and which it is not easy to get rid of. For this reason, the refined Sicilian sulphur is the only kind that is employed in this manufacture, at least in Britain.

Common sulphuric acid may be freed from the sulphates of lead and potash, which it generally contains, by distillation. This, however, though apparently a very simple process, is rather a nice matter to manage, according to the usual method. Sulphuric acid is not capable of being distilled at less than a red heat: when, therefore, the dense hot vapour first comes in contact with the necks of the retort and receiver, it is apt to break them, unless the precaution has been taken of thoroughly heating them by means of a pan of charcoal placed beneath, a minute or two before the distillation commences. All this risk, however, may be avoided, and in some laboratories it actually is so, by connecting the glass body, in which the acid is boiled, with the receiver, by means of a tube of platina. Boiling sulphuric acid has not the least action on this metal, and the vapour, in its passage through, becomes so far cooled and condensed, that it flows into the receiver in drops.

SULPHURIC Acid, in the *Materia Medica*, is a valuable tonic, astringent, and antiseptic. Its officinal preparations are the following; viz. *Acidum sulphuricum dilutum*; *acidum sulphuricum aromaticum*; *acid. citricum*; *acid. muriaticum*; *acid. nitricum*; *aqua super-carbonatis potassæ*; *fulphas potassæ*; *phosphas soda*; *urias antimonii*; *ferri sulphas*; *hydrargyri osymuriatis*; *sub-fulphas hydrargyri flavus*; *zinci sulphas*; and *ether sulphuricus*.

The *acidum sulphuricum dilutum*, or diluted sulphuric acid of the Lond. Ph., is obtained by adding a fluid-ounce and a half of sulphuric acid gradually to 14 fluid-ounces and a half of distilled water, and mixing. The Edin. Ph. directs one part of sulphuric acid to be mixed with seven parts of water. The Dub. Ph. orders 2 oz. by weight of sulphuric acid to be mixed gradually with 14 oz. by weight of distilled water, and the mixture to be set aside to cool; then the clear liquor to be poured off. The sp. gr. of this acid is to that of water as 1090 to 1000. The tonic and antiseptic powers of this acid render it extremely serviceable in low typhoid fevers, dyspeptic affections, diabetes, convalescencies, and in cutaneous eruptions. It restrains the colliquative sweats which attend hectic; locally applied, it is a common and useful adjunct to gargles in cynanche, and to check salivation; and as a refrigerant, it is given with certain benefit in passive hæmorrhages, from whatever part they may arise. In the first-mentioned cases the diluted acid may be combined with infusions of cinchona or other vegetable bitters, and aromatics; and in the latter, with infusion of roses, mucilage, or simple water sweetened with syrup. The usual dose is from ℥ x to ℥ xxx, but in malignant erysipelas, with a tendency to hæmorrhagy, it has been given to the amount of fʒj in twenty-four hours; and it has also been given with evident advantage, says Thomson, to the same amount, in violent uterine hæmorrhages.

The *acidum sulphuricum aromaticum*, or aromatic sulphuric acid of the Edin. Ph., is prepared by dropping 6 oz. of sulphuric acid gradually into 2 lbs. of alcohol; digesting the mixture in a covered vessel with a very gentle heat for three days; then adding of cinnamon bark, bruised, 1½ oz. and ginger root, bruised, 1 oz.; digesting again in a close vessel for six days, and filtering through papers placed in a glass funnel. The odour of this oil, which is generally regarded as an imperfect ether, is peculiar and aromatic, and its taste gratefully acid; it is limpid, and of a brownish colour. This is an agreeable mode of exhibiting sulphuric acid in dyspepsia, chronic asthma, and most of the complaints for which the diluted acid has been found serviceable. The dose may be from ℥ x to ℥ xxx in bitter infusions, or any convenient fluid vehicle, given three or four times a day.

The *acidum citricum*, or citric acid of the London Ph., is obtained by taking of lemon juice a pint, prepared chalk an ounce, or a quantity sufficient to saturate the juice, and nine fluid-ounces of diluted sulphuric acid: add the chalk by degrees to the lemon juice heated, and mix them; then pour off the liquor. Wash the citrate of lime which remains in repeated portions of water, and then dry it. On the dried powder pour the diluted sulphuric acid, and boil for ten minutes; express the liquor strongly through a linen cloth, and filter it through paper. Evaporate the filtered liquor with a gentle heat, so that crystals may form as it cools. To obtain the crystals pure, dissolve them in water a second and a third time; filter each solution, boil it down, and put it apart to crystallize. (See *CITRIC Acid*.) The solution of this acid in water, in the proportion of ʒj of the crystals to ℥j of water, answers nearly all the purposes of recent lemon juice; and is even preferable for forming the common effervescent draught with subcarbonate of potash. A solu-

tion of ʒij in ℥j of water, sweetened with sugar that has been rubbed on fresh lemon-peel, forms a grateful refrigerant beverage, resembling lemonade, and equally useful in febrile and inflammatory complaint. It is probable that the crystallized acid may be equally useful in scurvy as the fresh juice of the fruit; but we have not heard whether this point has yet been ascertained.

Acidum muriaticum, or muriatic acid of the London Ph., is prepared by taking of muriate of soda dried, 2 lbs.; 1½ lb. of sulphuric acid; and 1½ pint of distilled water; first mixing the acid with half a pint of the water in a glass retort; and when the mixture is cold, adding to it the muriate of soda; pouring the remainder of the water into the receiver; and, having fitted to it the retort placed in a sand-bath, distilling over the muriatic acid into this water, with a heat gradually raised until the retort becomes red-hot. The specific gravity of muriatic acid is to that of distilled water, as 1.170 to 1.000. The Edinb. Ph. directs to take of muriate of soda, 2 lbs.; of sulphuric acid, 16 oz.; and 1 lb. of water: first expose the muriate of soda in a pot to a red heat for a short time, and when it is cold, put it into a retort; then pour the acid, mixed with the water and cooled, upon the muriate of soda; and, finally, distil from a sand-bath with a moderate fire as long as any acid comes over. The Dub. Ph. directs to take of muriate of soda dried, sulphuric acid, and water, of each six pounds; to dilute the acid with the water, and after it is cold, to add it gradually to the muriate put into a glass retort; then to distil the liquor until the residuum becomes dry. (See *MURIATIC Acid*.) This acid is tonic and antiseptic. It has been efficaciously used in typhoid fevers, and in some cutaneous eruptions. It is a common and useful adjunct to gargles, in the proportion of from fʒls to fʒij in fʒvj of any fluid, in ulcerated fore-throats, and cancerum oris; and, in a very highly diluted state, ℥viij in fʒiv of water, it has been recommended as an injection in gonorrhœa.

This acid has even been regarded as an antidote in general syphilitic affections; but the observations of Mr. Pearson have shewed this opinion to be erroneous; yet, by its salutary effects on the stomach and general health, "it is a medicine capable of ameliorating the appearance of venereal ulcers, and of restraining for a time the progress of the disease," where it is desirable "to gain a little time, previously to the entering on a mercurial course." The dose is from ℥x to ℥xx in a sufficient quantity of water.

A very important property of muriatic acid, in the state of gas, is the power it possesses of neutralizing putrid triasmatas, discovered by Morveau in 1773. It is, therefore, used as an agent for destroying infection in sick rooms and hospitals, disengaged by pouring sulphuric acid on common salt.

Acidum nitricum. (See *NITRIC Acid*.) For the other articles above enumerated, see *ANTIMONY*, *IRON*, *MERCURY*, *POTASSA*, *SALIS*, *SULPHATE*, &c.

For an account of the *ether sulphuricus*, or sulphuric ether, see *SPIRIT*.

The ethereal oil of the Lond. Ph. is prepared in the following manner. After the distillation of sulphuric ether, distil again the remaining liquor with a gentle heat, until a black froth swells up; then immediately remove the retort from the fire. To the liquor in the retort add water sufficient, that the oily part may float upon it. Let this be skimmed off, and as much lime-water be added to it as will neutralize any acid it may contain; and shake them together. Lastly, take off the ethereal oil after it is separated. The oily ethereal liquor of the Dub. Ph. is obtained by taking what remains in the retort after the distil-

lation of sulphuric ether, and distilling to one half by a moderate heat; the product of both these processes is a thick oily matter, of a yellow colour, less volatile than ether, but soluble both in ether and alcohol. It may be obtained

more directly, though less economically, by distilling ether with a portion of sulphuric acid. It is used for the preparation of the compound spirit. See *SPIRIT of Ether*.

Tanning

TANNING, the art of converting the gelatinous part of the skins of animals into the substance called leather, by impregnating it with tannin or the tanning principle, in such a manner as to render it tenacious, durable, and impermeable to water.

It is difficult to say at what period the art of tanning was discovered. It was doubtless known to the ancients in some degree of perfection; and it is highly probable that the skins of animals were employed by man as a covering long before the art of tanning was known: but they would require in this state to be constantly kept dry, as moisture would soon bring them into a state of putrefaction.

The astringent matter, which converts the skin into leather, abounds in so many vegetables in every country, that accident would soon lead to some method of producing the change. Independent, however, of vegetables, many earthy and metallic substances have the property of rendering skins incorruptible to a certain extent; and some mineral waters containing copper or iron will occasion this change. Hence we may conclude that some means of giving preservation to the skins of animals must have been known at a very early period.

Though there has been no radical alteration or any great practical improvements in the art of tanning, yet for the last twenty or thirty years it has attracted the attention of many celebrated chemists and philosophers in all countries, who have investigated the subject with great accuracy and precision. Previous to this period we occasionally find some experiments and observations by men of science on the materials of tanning, as by the Hon. Charles Howard in 1674, (*Phil. Trans.* vol. ix.) by the abbé Nollet, Gesner, Gleditsch, Buffon, de la Lande, and others, in *Mem. Acad. Sc. Paris* and *Berlin*.

In the year 1765, the Society of Arts and Sciences in London granted a premium of 100*l.* for the discovery of a method of tanning with oak saw-dust; and in 1795 the Rev. G. Swayne suggested the use of oak leaves. It is unquestionably true that all those substances, and indeed every part of almost every vegetable in nature, possesses a certain portion of the tanning principle; but, exclusive of oak bark and two or three other well-known articles, the quantities of all the rest added together would be so inconsiderable, and the proportion of tannin contained in them so inadequate to the purposes of manufacture, that, except for philosophical curiosity and chemical experiment, they are unworthy of notice. As the theories of speculative minds they are ingenious and amusing, but they afford very little useful information on the nature and properties of

tannin, and have produced no beneficial results in practice.

Deyeux, about 1793, (*Annales de Chimie*, vol. xvii.) appears to be the first chemist who successfully explained the true principles of tanning; which afterwards, with more practical application, were still further developed by the labours of M. Seguin in 1795. Before his investigation of this subject, the theory of tanning was strictly mechanical. The astringency of vegetables, which produced the change in the skin, was considered as a resinous body, which had the effect of giving firmness to the fibres of the skin, and rendering it insoluble.

Seguin saw the operation in a chemical point of view: he examined the nature of the process scientifically, and discovered that the change which the skin underwent in the operation of tanning, was the result of a chemical union between a substance furnished by the vegetable employed, and the gelatinous part of the skin. These principles he confirmed, by combining the vegetable substance in question with the gelatine of a solution of isinglass.

It will be seen, from our article **TANNIN**, that the compound discovered by Seguin, and which is precipitated when an infusion of nutgalls is added to a solution of isinglass, is an insoluble substance, having many properties common to leather. See *Nicholson's Journal*, vol. i. p. 271. 4to.

The practice which M. Seguin founded upon his theory was generally admired. He first extracted the tannin from the vegetable, which was oak bark, and applied it to the prepared skin in a more concentrated form, with a view to impregnate it as speedily as possible with the tannin. This was said to be done with great success in one-third of the usual time, and to have produced superior leather. The fame of this discovery soon spread throughout Europe, and Mr. Desmoud, a man of education and intelligence in this country, took out a patent for the exclusive right of using M. Seguin's method of tanning.

Although this process of suspending the hides vertically in a very strong solution of bark saved much time, yet it was soon found to be adapted only to the thickest hides used for sole leather, and quite unfit for the lighter kind of skins which required flexibility and tenacity. This method, therefore, of Seguin's, however chemical and philosophical it might appear, did not answer in the result; and as it was attended with much additional expence, has never been generally practised in England.

It was not, however, till 1803, when sir Humphrey Davy (a name ever to be recorded in the annals of science with gratitude and admiration) began to investigate the sub-

ject, that the art of tanning was thoroughly understood, and reduced to scientific principles. He instituted a series of experiments on the various substances employed—examined their chemical affinities and agencies—their action upon animal matter, and combination with other bodies—and developed and explained the whole with a simplicity and perspicuity which forcibly elucidated the essential principles on which the art depends. If this elucidation has not been productive of any material improvements in the mode of manufacturing leather, it may perhaps be attributed more to the prejudices arising from long habit, than to any defect in the theory and demonstrations of that enlightened philosopher. And here it may be remarked, that these demonstrations and that theory derive additional importance, and are entitled to peculiar attention, from having been strongly confirmed and successfully practised by an intelligent and respectable manufacturer (now retired from business), to whom we are chiefly indebted for this article.

From these and other sources of information now open to the public, and from the general diffusion of knowledge among all classes, the man of science and the manufacturer are daily becoming more assimilated to each other; and if the latter should be taught to discard all unfounded prejudices, and to adopt more scientific principles, there is reason to believe that the various processes of the art of tanning may yet be capable of great practical improvement.

In the two valuable papers which Sir Humphrey Davy has given in the Philosophical Transactions for 1803, he considers the process of tanning as depending simply on the chemical union of the tanning principle with the matter of skin, so as to form an insoluble compound. He has shewn that Seguin's quick method of tanning is not the best; because the exterior strata of skin being perfectly combined with tannin, before the interior strata are materially acted upon, thereby prevent the latter in some degree from imbibing the full action of the solution. This renders the texture of the leather less equable, makes it harsh and brittle, liable to crack, and of course less durable.

Sir Humphrey thinks it probable that another substance, besides tannin, combines with the skin, namely, the extract, to which it owes much of its suppleness and tenacity—that the leather gets more of this substance from weak infusions of bark, than from the strong ones recommended by Seguin—that it is equally insoluble in water—and that, upon the whole, the methods now generally in use, may, with a few alterations, be considered the best.

The various discoveries pretended to have been made, and the numerous patents obtained for their use and application, have hitherto tended very little to the advancement of science or the progress of the art. This may fairly be inferred from the conclusion of the celebrated chemist above-mentioned. Indeed it appears by the specifications annexed to the patents, that most of these projected improvements purport to be either for the different construction and arrangement of the various pits—for the application of mechanical apparatus to diminish labour—or for extracting the tannin and warming the infusion by artificial heat, with a view to accelerate the process. These fancied improvements are only the idle theories and visionary projects of speculative minds: but as it may afford information to the curious, and furnish hints for future discovery, we subjoin

A List of Patents for Tanning.

1790. Anthony Fay, esq. of London, for a mechanical apparatus to diminish the labour of *handling*, to grind the

bark very small, and to concentrate it, by boiling, into a strong extract.

1794. Samuel Ashton of Sheffield, for tanning hides and skins with certain mineral productions. As such materials were prohibited by the statute of James I. an act of parliament was passed to legalize the use of them.

1795. Mr. Tucker of Wickham, Hants, for triple pits composed of wood, metal, and bricks, to keep up a constant fire at the bottom, to warm the infusion and expedite the process.

1796. William Desmond, esq. of London, for a new mode of tanning, according to M. Seguin's method, as before stated.

1797. Robert Cross of Lancaster, for pits on a new construction, to enable him to apply artificial heat and to tan quickly.

1799. Francis Brewin, esq. of London, for a peculiar construction and arrangement of pits, and for the use of machinery, &c.

1802. John Lawrence, for the use of oak saw-dust in tanning.

1802. Thomas Martin of London, for constructing pits on a new plan, &c.

1802. John Cant and John Miller of Montrose, for boiling the bark, &c. so as to extract the tanning principle more effectually.

1807. Robert John Stanley of Lincolnshire, for tanning light leather without bark, for a peculiar preparation previous to the application of ooze, and for boiling the materials of tanning.

1813. Sparks Moline, for the use of the solid extract of bark.

1815. Thomas Ashmore, esq. for the use of all kinds of foot, whether from coal, wood, peat, or bones, and the oils and empyreumatic liquors arising from them by distillation or combustion, to be applied to the purposes of tanning.

Of the utility of the last-named patent, we shall give no opinion at present; but of the remainder it may be affirmed that none of the methods therein recommended have ever been much practised: some of them which were adopted by a few individuals, were attended with considerable loss; and as most of them are now laid aside, we may reasonably conclude that they have not proved beneficial to the projectors or to the public.

Before we describe the present method, it may be necessary to premise, that in different parts of the kingdom, the same terms and denominations are sometimes employed to designate distinct kinds of leather: but all tanned leather is technically classed and universally known under two general denominations; namely, *hides* and *skins*. The former term being commonly applied to the larger animals, as bulls, oxen, cows, &c. which are chiefly intended for the soles of stout shoes, and other purposes requiring very thick and solid leather; while the latter term is used for calves, seals, &c. which, being thinner and more flexible, are intended for the upper leathers of shoes and boots, for saddles, harness, &c.

The heaviest and stoutest of the bull and ox hides are generally selected to make what are technically called *butts* or *bucks*, and are manufactured in the following manner.

When the horns, &c. have been removed, the raw hides are laid on a heap for two or three days, and are then suspended on poles in a close room, called a *smoke-house*, which is heated somewhat above the common temperature by a smouldering fire: this occasions incipient putrefaction,

which loosens the epidermis, and renders the hair and other extraneous matter easy of separation from the true skin. This is effected by extending the hide on a wooden horse or beam of a convex form, and scraping it with a large two-handed knife, called a *fleying-knife*, which is bent, to suit the convexity of the beam.

The hides are then immersed in a pit containing water slightly impregnated with sulphuric acid. This operation, which is called *raising*, by distending the pores and swelling the fibres, prepares the hide for the reception of the tannin, and renders it more susceptible of its action.

When the hides are sufficiently *raised*, they are removed into a pit, in which they are lain smooth with a stratum of oak bark ground to a coarse powder between each.

The pit is then filled with the tanning lixivium or ooze, prepared from oak bark and water, and the hides remain a month or six weeks without being moved. At the end of this time, the tanning principle being exhausted, the ooze and spent bark are taken out of the pit, and the hides put in again, stratified with fresh bark, and covered with fresh ooze as before. Here they remain about three months, when the same process is repeated, at about the same intervals, three several times or more, according to the strength of the lixivium and the substance of the hides. When sufficiently tanned, they are taken out of the pit, hung up in a shed to dry gradually, and being compressed with a steel instrument, and beaten smooth to render them firm and dense, the operation is complete; and having been numbered, weighed, and stamped by the excise officer, to ascertain the amount, and denote the payment of the duty (which will be noticed at the end of this article), they are ready for sale, and are termed *butts* or *backs*. These form the thickest and most substantial sole leather for very strong shoes, and are chiefly intended for exportation.

Crop hides are thus manufactured. The horns having been removed, the hides are immersed in pits containing a mixture of lime and water, where they remain three or four days, being occasionally moved up and down, that each part may be uniformly exposed to the action of the lime-water. They are then taken out of the lime-pits, and the hair and other extraneous matter being scraped off on a wooden beam, as before described, are washed in water, to free them from the lime and filth adhering. They are now immersed in a weak ooze, and by degrees are removed into other pits, containing solutions gradually increasing in strength, during which time they are taken up and put down (technically termed *handling*) at least once in every day, that all parts of the hide may be acted upon by the tanning principle equally and uniformly. This is continued for about a month or six weeks, when they are put into other pits with stronger ooze and a small portion of ground bark; from whence, as the tannin becomes exhausted, they are removed to other pits in regular succession, with fresh ooze and fresh bark, for two or three months.

At the end of this period, the hides are put into larger vats, called *layers*, in which they are stratified, or lain smooth, in a lixivium of greater strength, and with a larger quantity of ground bark between each fold. Here they remain about six weeks, when they are taken up and relaid in the same manner, with fresh bark and strong ooze, for two months. This process is repeated, with little variation, once, twice, or thrice, at the discretion of the manufacturer, till the hides are thoroughly tanned; when they are taken out of the pits, suspended on poles to dry, and being compressed and smoothed, nearly in the manner before described, are called *crop hides*, and form the principal part of the sole leather which is used in England.

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The process of tanning *skins* (calves, seals, &c.) is somewhat different from *hides*. They are continued in the lime-pits for ten or fifteen days; they are then depilated and washed in water, after which they are immersed in an infusion of pigeon's dung, called a *grainer*, having the property of an alkali. Here they remain for a week or ten days, according to the state of the atmosphere and other circumstances, during which time they are frequently *handled*, and scraped on both sides upon a convex wooden beam. This scraping, or *working*, as it is termed, with the action of the *grainer*, helps to discharge all the lime, oil, and saponaceous matter, and renders the skin soft and pliant, fitted to imbibe the tanning principle. They are now removed into pits containing a weak solution of bark, where they undergo nearly the same process of handling, &c. as *crop hides*; but they are seldom stratified in *layers*; and the time occupied in tanning them is usually from two to four months, according to their nature and substance. The skins are then dried, and sold to the currier, who dresses and blacks them for the upper leathers of boots and shoes, for harness, and various other purposes.

The light and thin sort of cow-hides and horse-hides undergo nearly the same process in tanning as calf-skins, and are applied to similar uses.

These processes are such as are now commonly practised, varying, however, with the nature and condition of the peculiar kind of hides and skins—with local habits and circumstances—and with the skill and experience of the manufacturer. The greatest defect in the common methods appears to exist in the means of extracting the tannin from the bark. Cold water is chiefly used for that purpose; but some persons conceiving that this does not entirely exhaust the tanning principle, subject the bark, as before observed, to the action of boiling water, &c. If, however, as sir Humphrey Davy has stated, the extract as well as the tannin combines with the skin, the extraction of the tannin by heat would tend to oxygenate the former, and render it insoluble in the liquid.

The late ingenious Dr. Macbride of Dublin invented and published in 1778 a new method of tanning, the leading feature of which was the use of lime-water, which he conceived would extract the virtues of oak bark more completely than plain water.

It has, however, been observed, that both natural and artificial tannin form compounds with the alkalies and the alkaline earths, and these compounds are not decomposable by skin. Lime forms with tannin a compound not soluble in water, and therefore Dr. Macbride's system is founded on erroneous principles, as so much of the tannin as combined with the lime contained in the water was lost. It was also found, by the practical experience of tanners, that this method was in all respects injurious rather than beneficial; and as it has long been universally rejected, it is not necessary to enter into the detail. The reader who is desirous of further information on this point, may refer to Phil. Trans. vol. lxxviii. part i. art. 8.

The application of some new and cheap substitute for oak bark has been long a desideratum in tanning. Catechu, the substance we have spoken of under the article TANNIN, has been recommended, and its powerful tanning properties have been fully ascertained by experiment and actual practice: but it is not likely that the article can be procured in sufficient quantity, or at an adequate price, for the purposes of manufacture. The bark of elm, willow, larch, and other trees, together with *vallonia* (the acorn of a peculiar species of oak in Turkey), have all been employed in tanning with considerable effect.

The greatest hope which chemical science presents, is the

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probability that the tanning principle will, at some future period, be formed artificially in such quantities and at such expense as will admit of its general application to practical purposes. The important discovery of Mr. Hatchett already goes far towards the accomplishment of this object. He has distinctly ascertained that a substance very analogous to tannin may be produced by exposing carbonaceous matter, whether vegetable, animal, or mineral, to the action of nitric acid; and has actually converted skin into leather by deal saw-dust, asphaltum, pit-coal, wax-candle, and even by a part of the same sort of skin itself. The changes produced in these bodies, by disuniting and recombining their elementary principles, may by further developement lead to a more economical process of tanning, and thus render essential service to the arts and manufactures.

Tanned leather is subject to a very heavy excise duty. In the ninth year of queen Anne, a duty of 1*d.* *per lb.* was laid on all hides and skins tanned in Great Britain. In the following year an additional $\frac{1}{2}$ *d.* *per lb.* was imposed. Thus it remained, amidst all the financial difficulties of successive systems. But if a different mode of taxation and collection (as in Ireland, on the admeasurement of the pits; or on the raw material, or any other plan) could be adopted, the benefits which would result, both to the manufacturer and to the community, are incalculable. It would leave the tanner at full liberty to conduct his business entirely according to his skill and judgment, and to unite with it the trades of currier and leather-cutter, which are so naturally connected with his own. It would enable him to facilitate the process; to save much superfluous labour; to economize the materials of tanning, which are now unavoidably wasted on useless or inferior leather; to shave, divide, select, and appropriate certain hides and skins, or parts of hides and skins, at the proper time for their peculiar purposes; to prevent the injury which leather often receives in drying at particular seasons; and ultimately to improve the quality and reduce the price of one of the most useful articles of general consumption.

These are matters well worthy the consideration of the executive government and the legislature. Some attention has already been given to this subject by the house of commons in the sessions of 1815 and 1816, and we have no doubt that by further investigation, intelligent and unprejudiced persons might easily arrange and complete a plan which would afford perfect security to the revenue, would simplify the collection, would prevent the possibility of fraud, and at the same time prove extremely beneficial to the manufacture and to the public.

chancellors of the exchequer, till 1812, when, by the act 52 Geo. III. c. 94. a further duty of 1 $\frac{1}{2}$ *d.* *per lb.* was added, making the whole duty on tanned hides and skins 3*d.* *per lb.* The annual revenue arising therefrom now amounts to upwards of 500,000*l.*

It may not be improper here to remark, that the excise duty on leather tanned in Ireland, is levied and collected in a different manner.

The act 40 Geo. III. c. 9. passed in Ireland in 1800, instead of imposing a certain duty *per* pound weight, as in England, on all hides and skins tanned with oak bark, imposes a duty of nine pence by the year, for every cubic foot contained in all the pits in the yard of the tanner, allowing a deduction of two-ninths for certain pits called *latches*, which are used solely for the purpose of preparing the *lixivium* or *ooze*. By this act the tanner was permitted, on giving certain notice, to discontinue not less than one-fourth, and by 43 Geo. III. c. 97. not less than one-eighth for six months, receiving a proportionate deduction from his monthly payments of the duty. By the 48 Geo. III. c. 62. those acts were made perpetual.

Previous to the passing the Irish act 40 Geo. III. the writer of this article was consulted by the then chancellor of the exchequer in Ireland, on the relative amount of the intended duty of nine pence *per* cubic foot; and upon accurate calculation it was found to bear a fair proportion to the duty then existing in England. If the present duty on leather tanned in this part of the united kingdom were proportionably commuted on a similar plan, it would materially tend to the progress of the manufacture.

The chief obstacle to great practical improvement is the excise duty—not so much from its amount (though that is very considerable), as from the mode in which it is now levied and ascertained, namely, by weight, when the leather is dry and fit for sale. This mode necessarily requires a system of rules and regulations, which, from their multiplicity and complicated nature, subject the manufacturer to daily inconvenience, and to occasional hardships. For, notwithstanding the repeal of the oppressive act 1 James I. cap. 22, and other subsequent statutes, the tanner is still restricted, by various excise laws, from advantageously shaving and reducing his hides and skins—from mixing and removing them at his discretion—and also from exercising the trades of a currier, &c.

Those restrictions, it must be acknowledged, are in some degree necessary for the protection and security of the revenue, while the duties are imposed and collected upon the present

Tar

TAR. See **PAMLICO.**

TAR, or *Tarr*, a thick dark-brown or black resinous adhesive juice, issuing from the wood and bark of old pines or firs, either naturally, or by burning. See **PINUS.**

Some modern writers inform us, that tar flows from the trunks of pines and firs, when they are very old, through incisions made in the bark near the root; that pitch is only tar inspissated; and both are the oil of the tree grown thick and black with age and the sun. The trees, like old men, being unable to perspire, and the secretory ducts obstructed, they are, as one may say, choaked and stuffed with their own juice. But the method used by our colonies in America of making tar and pitch, is, in effect, the same with that of the ancient Macedonians; as appears from the account given in the Philosophical Transactions. And the relation of Leo Africanus, who describes, as an eye-witness, making of tar on mount Atlas, agrees in substance with the methods used by the Macedonians of old, and the people of New England of this day. The greater part of the tar imported into Britain is brought from the Baltic, and is still prepared in nearly the same method which is described by Dioscorides as having been practised by the ancients. The branches of the trees are cut into billets, and piled up in large stacks, which are covered with turf. Fire is then applied to the wood, and it is suffered to burn with a slow smothered flame, during which process the tar is formed by the decomposition of the resinous juice, which flows to the bottom, and runs out through a small channel cut for the purpose. The stacks are generally built on the slope of a hill, so that the tar is easily collected, and put into barrels; in which state it is brought into this country. The process now described is termed "*distillatio per descensum.*" See **PINE.**

A more expeditious and economical method of obtaining tar is practised in France and Switzerland. The wood is heated in large brick ovens, constructed for the purpose, and thus it is charred more equally, and the tar is of a more uniform and better quality. In the Vallais the pines are felled in the preceding year, that the wood may be sufficiently dry, and when the outer bark and twigs are stripped off, the remainder of the tree is cut into billets of tolerably equal size. The oven is constructed of stone or brick, of the shape of an egg placed on its small end: the floor is made either of a flat stone, scooped out into a hollow, or of several stones accurately joined together. On one side of it, about five inches above the lowest part, is a hole, in which a gun-barrel is thrust, and this serves to convey off the liquid tar that is collected. A large iron grate is laid

at the bottom of the oven. The largest of these ovens are about ten feet high, and five or six feet in the largest diameter. In charging the oven, bundles of billets are thrown in and spread as evenly as possible, the interstices being filled with chips, till the charge nearly reaches the top. The whole is then covered with a layer of chips, and the top of the furnace is closed with flat stones heaped upon one another, gradually lessening the opening, and forming a kind of vaulted chimney, the mouth of which is four or five inches across. The dry chips at the top of the furnace are then set on fire, and the heat spreads downwards, till the whole charge is sufficiently kindled. The chimney is then entirely closed with a large stone, and wet earth is heaped on the stones at top, and thrown on wherever the smoke is observed to burst out too strongly. The melting then begins, and the tar falls to the bottom, fills the hollow of the floor (which detains any bits of wood and other impurities), and runs off through the gun-barrel into casks placed for receiving it. The fire must be occasionally refreshed by letting in a small draught of air through small holes left for the purpose in the sides of the kiln. When the process is finished, the wood, completely charred, is taken out, and the oven, after having been cleared out, is again filled. The red wood and knots, being the richest in resin, are found to yield about one-fourth of their weight of tar; but the general average product is about 10 or 12 *per cent.* of the weight of the whole charge. After each process, a quantity of "lamp-black" is collected beneath the stones that form the vault of the temporary chimney.

According to Theophrastus, not only the turpentine-trees, the pines, and the firs yield resin or tar, but also the cedars and palm-trees; and the words *pix* and *rosin* are taken by Pliny in so large a sense, as to include the weepings of the lentiscus and cypress, and the balms of Arabia and Judæa; all which perhaps are near of kin, and in their most useful qualities concur with common tar, especially the Norwegian, which is the most liquid and best for medicinal uses. Those trees that grow on mountains, exposed to the sun or north wind, are reckoned to produce the best and purest tar; and the Idæan pines were distinguished from those growing on the plain as yielding a thinner, sweeter, and better scented tar. Every part of the tree, which is at all resinous, is fit for yielding tar; but the red wood and the hard roots yield the best in quality as well as the greatest in quantity.

Every kind of wood will produce the *pyroligneous acid* (which see), and tar by the destructive distillation. Peat also will yield it in abundance.

There is also a kind of tar, the project of making which was suggested by Becher, the celebrated chemist, in the time of king Charles II., which has for several years been prepared from coal in the bishopric of Liege, and in other parts of Germany: we also make considerable quantities in England, especially near Broseley, in Shropshire, and at Bristol. In the bishopric of Liege the coal is distilled in a kind of still, composed of two large cast-iron pots. In England the coal is put into ovens, which are heated by fires lighted under their bottom, and the liquid matter is forced through an iron pipe inserted into the top of the oven, and which communicates with proper condensing vessels. Watson's Chem. Ess. vol. ii. p. 346, &c.

The earl of Dundonald, in Scotland, has lately invented the art of extracting tar and pitch from pit-coal, by a new process of distillation. See Address and Proposals by sir John Dalrymple, 1784.

A substance resembling tar, called "brai-gras," and much used by the French for careening ships, is made in the following manner. The oven, described in the preceding part of this article, is charged with alternate layers of chips of green wood, and billets of dry, and all the refuse matter of turpentine, &c. Over the whole is laid a stratum of "brai-hee," or rosin, and the gun-barrel pipe is stopped up, and not tapped till the whole of the wood is reduced to charcoal. The vault of the oven is also covered more carefully after the charge is sufficiently kindled, and the whole process is carried on more slowly, and the heat of the fire melts the rosin at the top, which mixes with the resinous sap, and the whole concretes into a dark resinous liquid at the bottom. When it is sufficiently cooled, it is drawn off and barrelled. This "brai-gras" is of an intermediate consistence between tar and rosin. Aikin's Dict.

Tar is properly an empyreumatic oil of turpentine, and has been much used as a medicine both internally and externally.

Tar in substance, mixed with honey, has been found an excellent medicine for coughs.

The ancients esteemed tar good against poisons, ulcers, the bites of venomous creatures; also for phthical, scrofulous, paralytic, and asthmatic persons. But the method of rendering it an inoffensive medicine, and agreeable to the stomach, by extracting its virtues in cold water, was unknown to them. Siris, sect. 9. 16, 17. 21. 28. See *TAR-water*, infra.

Tar is sometimes given in substance, mixed with so much powdered liquorice, or other such powdery matter, as is sufficient to render it of a fit consistence to be formed into pills. An ointment of tar has been directed in the pharmacopeias, which has been chiefly employed in cutaneous disorders. See *UNGUENTUM à Picæ*.

Dr. Cullen mentions an empirical practice, with respect to tar, which is as follows. A leg of mutton is laid to roast, and whilst it is roasting it is basted with tar. Whilst the roasting is continued, a sharp skewer is frequently thrust into the substance of the mutton, so that the gravy may run out: with a mixture of the tar and gravy found in the dripping-pan, the body is to be anointed for three or four nights successively, and during the time the same linen is to be worn. This is alleged to be a remedy in several cases of lepra; and Dr. Cullen knew one instance of its having been employed in a lepra ichthyosis with great success; but he had no opportunities of repeating the practice.

But the chief use of tar is for paying the sides of ships and boats, and their rigging, in order to preserve them from the effects of the weather, which would otherwise crack or rot them.

The tar obtained from the deposition of pyroligneous acid has been recommended as the best preservative for every kind of wood-fence. For this purpose, it should be gently heated in an iron pot, and laid on with a brush. It soaks into the wood, and seems to leave no body, as the artists express it; but after some days' exposure to the sun, the surface and texture of the wood will be much altered; for it will be found so impervious and hard, that it will be very difficult to make any impression upon it. If a second, and especially if a third coat of this tar be put upon wood, it will then *bear out*, as the painters call it, sufficiently well; and Mr. Parkes is of opinion that it will preserve all outside wood-work much more effectually than any other means that have hitherto been employed for the purpose. For ornamental paling, and all outside work, a first, and perhaps a first and second coat of this tar might be used with great advantage; and when these are dry, white lead and oil might be used to finish the work. This substance not only hardens the wood, but effectually preserves it from worms and from all other insects. It will stop the progress of decay, when wood has become worm-eaten. It is observed, however, that this tar is very different from that which is distilled from mineral coal, but which the earl of Dundonald recommended for a similar purpose. The appearance of the application may be very considerably improved by the following preparations; viz. 1 gallon of tar, 1 oz. of tallow, 2 oz. of pulverized rosin, melted together and put on warm;—or, 1 gallon of the tar and 2 oz. of pulverized sulphate of iron, used as the other. This tar has also been found an useful varnish for articles made of rolled iron, or of cast-iron. A beautiful varnish for these purposes may be formed by intimately mixing in a gentle heat one gallon of the wood-tar with half a pint of rectified spirits of wine. If this be laid on hot and properly hardened, it will prove a beautiful and durable black varnish. Parkes's Chem. Ess. vol. ii.

Tar may sometimes be found useful as an application for cuts in sheep by clipping, and also to the parts affected by the fly; as well as in those of many other sorts of animals. It is likewise applied to the axles of wheel-carriages, in order to prevent friction, and might probably be still more beneficially made use of in this intention, by having a portion of black-lead incorporated with it, as it would last longer, and be, at the same time, more powerful in obviating the effects of friction.

It is a material which has also been recommended for being applied to the parts of trees from which boughs are taken; in which cases, the faces of the wounded parts and the edges of the bark are to be made perfectly smooth by means of a proper knife; and in a few hours afterwards, or as soon as the parts are become quite dry, they are to be carefully plastered over with the tar, which is similar to that employed for smeared of sheep; or they may be laid over with white or blue lead paint, well mixed with oil, and made rather thicker than that commonly used in painting. The tar is, however, certainly preferable, being of a more adhering, healing nature; and, when laid on in a thin state, is not so apt to fall off in a scaly manner by the action and effects of the weather, as is the case with the other substances.

As the component parts of vegetable tar have been found to consist of oil, resinous matter, pyroligneous acid, and water; that which is of the finest brown colour, has the least acridity, and which is the freest from a dark black appearance, is probably the best and most proper for use in applications as dressings to animals; though the other kinds may be equally or more beneficial in different other intentions.

Tar, when in intimate mixture and union with butter or lard, and the different precipitates of mercury or sulphur,

forms an excellent application in different diseases of various kinds of animals, especially those of the skin.

TAR, Barbadoes. See BITUMEN, and PETROLEUM Barbadoense.

TAR, Mineral. See BITUMEN.

TAR-Water. As the cold infusion of tar has been formerly much in vogue, and has been recommended by one of the most learned and ingenious writers of the age, it may not be improper to give some account of its virtues from the bishop of Cloyne's *Siris*, so long as the tar continues to impregnate the water sufficiently, which will appear by the smell and taste.

In some parts of America, tar-water is made by putting a quart of cold water to a quart of tar, and stirring them well together in a vessel, which is left standing till the tar sinks to the bottom. A glass of clear water being poured off for a draught, is replaced by the same quantity of fresh water, the vessel being shaken, and left to stand as before. And this is repeated for every glass, so long as the tar continues to impregnate the water sufficiently, which will appear by the smell and taste.

But as this method produces tar-water of different degrees of strength, the author says he chuses to make it in the following manner: Pour a gallon of cold water on a quart of tar, and stir and mix them thoroughly with a ladle or flat stick, for the space of three or four minutes; after which the vessel must stand eight-and-forty hours, that the tar may have time to subside; when the clear water is to be poured off, and kept for use, no more being made from the same tar, which may still serve for common purposes.

This cold infusion of tar hath been used in some of our colonies as a preservative or preparative against the small-pox, which foreign practice induced the bishop to try it in his own neighbourhood, when the small-pox raged with great violence. He says the trial fully answered his expectation; all those within his knowledge, who took the tar-water, having either escaped that distemper, or had it very favourably. Several were preserved from taking the small-pox by the use of this liquor; others had it in the mildest manner; and others, that they might be able to take the infection, were obliged to intermit drinking tar-water. He says, he has found it may be drank with great safety and success for any length of time, and this not only before, but also during the aforesaid distemper.

The general rule for taking it is, about half a pint night and morning, on an empty stomach, which quantity may be varied according to the case and age of the patient; provided it be always taken on an empty stomach, and about two hours before or after a meal.

It has been found, that several persons infected with cutaneous eruptions and ulcers were immediately relieved, and soon after cured, by the use of this medicine. It is said, that even in the foulest distempers, it proved much more successful than salivations and wood-drinks had done. It also succeeded, beyond expectation, in a tedious and painful ulceration of the bowels, in a consumptive cough, and (as appeared by expectorated pus) an ulcer in the lungs, in a pleurisy and peripneumony. And when a person who had been for some years subject to erysipelatos fevers, perceived the usual forerunning symptoms to come on, the drinking of tar-water prevented the erysipelas.

Tar-water cures indigestion, and gives a good appetite. It is an excellent medicine in an asthma; it imparts a kindly warmth, and quick circulation to the juices, without heating, and is therefore useful, not only as a pectoral and balsamic, but also as a powerful and a safe deobstruent in cachectic and hysterical cases. As it is both healing and diuretic, it is very good for the gravel. The bishop says he

believes it to be of great use in a dropsy, having known it cure a very bad anasarca in a person whose thirst, though very extraordinary, was in a short time removed by the drinking of tar-water. From the success of this medicine in five or six instances, the bishop believes it to be the best and safest, either for preventing the gout, or for so strengthening nature against the fit, as to drive it from the vitals.

It may likewise be safely used in inflammatory cases; and, in fact, hath been found an admirable febrifuge, at once the safest cooler and cordial.

The salts and more active spirits of tar are got by infusion in cold water; but the resinous part is not to be dissolved thereby. Hence the prejudice which some, perhaps, may entertain against tar-water, the use of which might inflame the blood by its sulphur and resin, as a medicine, appears not to be well grounded. It is observed by chemists, that all sorts of balsamic wood afford an acid spirit, which is the volatile oily salt of the vegetable. Herein is chiefly contained their medicinal virtues; and this author affirms, that by the trials he has made, it appears that the acid spirit in tar-water possesses the virtues, in an eminent degree, of that of guaiacum, and other medicinal woods.

It is certain tar-water warms, and therefore some may perhaps still think it cannot cool. The more effectually to remove this prejudice, let it be farther considered, that, as on one hand, opposite causes do sometimes produce the same effect; for instance, heat by rarefaction, and cold by condensation, do both increase the air's elasticity; so, on the other hand, the same cause shall sometimes produce opposite effects. Heat, for instance, in one degree thins, in another coagulates, the blood. It is not therefore strange, that tar-water should warm one habit and cool another; have one good effect on a cold constitution, and another good effect on an inflamed one; nor, if this be so, that it should cure opposite disorders.

A medicine of so great virtue in so many different disorders, and especially in that grand enemy the fever, must needs be a benefit to mankind in general. There are nevertheless three sorts of people to whom the bishop says he would peculiarly recommend it; sea-faring persons, ladies, and men of studious and sedentary lives. See *Two Letters from the Bishop of Cloyne, &c.* published in 1747.

If it be asked, what precise quantity, or degree of strength, is required in tar-water? It is answered, that the palate, the stomach, the particular case and constitution of the patient, the very season of the year, will dispose and require him to drink more or less in quantity, stronger or weaker in degree. Precisely to measure its strength by a scrupulous exactness, is by no means necessary.

It is to be observed, that tar-water should not be made in unglazed earthen vessels, these being apt to communicate a nauseous sweetness to the water.

The same ingenious author recommends tar-water in the plague, and for the distemper among the horned cattle; with what success, must be left to experience.

Though this medicine, says Dr. Lewis, is undoubtedly very far inferior to the character that hath been given of it, it is apparently capable of answering important purposes, as a deobstruent balsamic solution, moderately warm and stimulating. It sensibly raises the pulse, and increases either perspiration or the grosser evacuations. He adds, "I have been informed of some late instances of its good effects in disorders of the leprous kind." *Mat. Med.*

Dr. Cullen thinks that the acid principle gives the virtue to tar-water, and on this account the bishop of Cloyne properly preferred the Norway tar to that of New England, as the former contains more acid than the latter. This eminent

physician acknowledges that he found this preparation in several cases to be a valuable medicine ; and that it appeared to strengthen the tone of the stomach, to excite appetite, to promote digestion, and to cure all symptoms of dyspepsia. At the same time, it manifestly promotes the excretions, particularly that of urine. From all these operations, it will be obvious, as the doctor thinks, that in many disorders of the system this medicine may be highly useful. Lewis. Woodville.

It has been lately observed by Dr. Darwin, that the watering of ground with tar-water is capable of destroying the white slug, which is so highly destructive to vegetables.

TAR-Kettle, in *Rope-Making*, is made of copper, and holds from ten to twenty barrels of tar. It is set in strong brick-work, and over it is fastened, from side to side, in the direction of the nipper, a bridge, made of three-inch oak-plank, thirteen inches

broad, through the middle of which is a mortise for the step to go through, to keep the yarn down and clear of the bottom, when drawing through the kettle. On the side of the kettle next the capstern, is an upright post, twelve inches square, in which is fixed a nipper to press the tar out of the yarn ; and a staff, with a weight suspended at the end, is fixed on the side of the nipper to keep it down, that the yarn may imbibe no more tar than is necessary.

TAR-Rope, a term used to signify tarred rope, or rope-yarn, such as the thread of old cables, &c. This sort of tar-rope is useful for a great number of different purposes, such as those of tying up the wads or sheaves of beans in the field, and many other similar articles ; the fastening of plants and trees to various kinds of supports ; and for being applied to a variety of other little uses of the more domestic kind, as being cheap and readily procured.

Teasel

TEASEL, or TEAZEL, in *Botany*. See *DIPSACUS*.

Beside the common wild species of this plant, there is a large kind of it, the heads of which are of singular use in raising the nap upon woollen cloth, for which it is propagated in great quantities in many parts of the west of England.

The soils most adapted to the growth of this plant are those of the more strong and deep kinds, but which are not too rich; as loamy clays, and such as have strong marly bottoms, and are fit for the growth of wheat crops.

The most favourable situations are those that are rather elevated, open, and incline a little to the south; and the higher grounds, particularly where the country is inclosed, are the most advantageous.

For the preparation of the ground, where it is a lea, it should be ploughed up deeply in the early part of the year, as in the beginning of February; and where it is inclined to moisture, it should be executed in narrow ridges of not more than three bouts each, the furrow slices being laid over in as even and regular a manner as possible, the fine mould from the furrows being raised by the plough or spade so as to cover the surface. But in lands that are sufficiently dry, and which are broken up from stubble, the ploughing may be deferred to a later period, and be laid in ridges of much greater breadths, and in a more flat form.

Mr. Billingsley, in his *Agricultural Report of Somersetshire*, has remarked, that in the providing seed, it should constantly be taken from such plants as are the most perfect of their kind, and the most productive in heads; as there is much difference in the quantity that is afforded by different plants, some producing nearly a hundred, while others do not afford more than three or four. It should be suffered to remain till it becomes perfectly ripened, and be used while fresh.

With respect to the proportion of seed, that which is mostly employed on the acre is from about one to two packs, according to the above writer; but some make use of a larger quantity, as two packs, or more.

It may be noticed, in regard to the season of putting in crops of this sort, that it is commonly about the middle of March or beginning of April. The common method of putting this sort of crop into the ground is the broad-cast, it being sown evenly over the surface, in the manner that is practised for turnips, sown in this way. But before this is done, the land should be well harrowed down, in order to afford a fine state of mould as a bed for the seed. It is then to be covered in by a slight harrowing with a light short-tined harrow, such as is used for grass-seeds. Some, however, prefer a light bush-harrow for this purpose.

However, this sort of crop may be sown in rows in the drill method, at the distance of eight, twelve, or more inches from each other, in the same way as that of the drilled turnip. But this method is not, we believe, yet much employed by those who are in the practice of raising crops of this nature.

In the after-culture of crops of this kind, much depends on the land between the plants being kept perfectly clean and free from weeds; in having them set out to proper and sufficient distances, as about twelve inches; and in having them well earthed up. Some cultivators perform frequent diggings, that the ground may be rendered cleaner and more mellow, consequently the growth of the plants be the more

effectually promoted. This business has usually the name of spaddling, or spitting, and is executed with great dispatch by labourers that are accustomed to perform it. When these diggings have been finished, nothing further is necessary till the period of cutting, which is generally about the end of the month of July in the second year, which is known by some of the uppermost heads beginning to blow; as when the blossoms fall, they are ripe, and in a state to be cut and secured.

This cutting is mostly executed at three different times, at the distances of about ten days or a fortnight from each other. It is performed by means of a knife, contrived for the purpose, with a short blade, and a string attached to the haft. This last is done, in order that it may be hung over the hand or wrist, when the leaves are to be stripped from the stem parts. A pair of strong gloves is likewise necessary. Thus prepared, the labourer cuts off the ripe heads along the rows or lines, or otherwise, with about nine inches of stem, and ties them up in handfuls with the stem of one that is more perfectly ripened, or otherwise. And on the evening of the day on which they are cut, they should be put into a dry shed; and when the weather is fine, and the air clear, they should be taken out and exposed to the sun daily, till they become perfectly dry. As soon as they are completely dried, they should be laid up in a dry room, in a close manner, till they become tough and of a bright colour, and ready for use. They should then be sorted or separated into three different kinds, by opening each of the small bundles. These are distinguished into *kings*, *middlings*, and *scrubs*, according to their different qualities. They are afterwards, the author of the above report says, made into packs, which, of the first sort, contain nine thousand heads; but when of the second, twenty thousand; the third is a sort of very inferior value. By some, before forming them into packs, they are done up into what are termed *staves*, by means of split sticks, when they are ready for sale.

The produce in crops of this nature must be very uncertain, there being sometimes fifteen, or sixteen, or more packs on the acre; and at other times scarcely any. The produce is disposed of to the cloth manufacturers in Somersetshire, Wiltshire, and Yorkshire.

It has been stated, that formerly an acre of land, if well grown, and what is deemed a full crop, often produced nine packs of *kings*, nineteen of *middlings*, and two of *scrubs*.

In the county of Essex, they have a singular practice of cultivating and growing teasel crops with seeds, such as coriander and carraway, producing thereby a sort of treble crop. It is stated, that the seeds of these several plants are sown together, very early in the spring, upon a strong old lay, once ploughed; and generally yield very considerable returns.

It is noticed, that the head of the teasel is of a conical form, two or three inches in length, and one or one and a half in diameter at the bottom, or largest end; armed on every part with small strong points, turned a little downwards; and are bought by the woollen manufacturers, who fix them upon frames, calculated to cover a cylinder, which is made to turn round, and slightly catch their says, bays, and other such articles, which another part of the weaver's machine draws against them; by which means the knap is raised to almost any length the manufacturer wishes.

The largest burs, and those most pointed, are esteemed.

the best, and are now called *male teasels*; they are mostly used in the dressing and preparing of stockings and coverlets; the smaller kind, properly called the *fullers'* or *drapers'* teasels, and sometimes the *female* teasel, are used in the preparation of the finer stuffs, as cloths, rateens, &c. The

smaller kind sometimes, called *linnets heads*, are used to draw out the nap from the coarser stuffs, as bays, &c.

The leaves of the common wild teasel dried, and given in powder or infusion, have been commended by some as a powerful remedy against flatulencies or crudities in the stomach.

Tempering

TEMPERING, in the *Mechanic Arts*, the preparing of steel and iron, so as to render them more compact, hard, and firm; or even more soft and pliant; according to their respective occasions.

Their metals are tempered by plunging them, while red-hot, into some liquor prepared for the occasion: sometimes pure water is used for that purpose: our locksmiths, &c. scarcely use any other.

When an instrument has been properly hardened, it is necessary to give it a certain degree of softness, in order to adapt it for the purpose to which it is to be applied. With this view, it should be heated again to a certain point, usually determined by its colour, and then instantly plunged into cold water. This is called "letting it down to the proper temper." It has been a question of difficult solution, how the water acts in hardening iron and steel. It is well known, says Mr. Parkes, in his "*Chemical Essays*," (vol. iv.), that the hotter any piece of iron is made, and the more quickly it is cooled, the harder it will become in its texture; and he suggests that this may be owing to the loss of its latent heat. In confirmation of this conjecture he alleges, that iron and steel are generally allowed to owe their malleability to their latent heat.

A composition of divers juices, liquors, &c. has sometimes been used; which is various according to the opinion and experience of the workman: as vinegar, mouse-ear water, nettle or Spanish radish-water, the water coozing from broken glasses, suet, salt, oil, foot, distilled wine, sal ammoniac, urine, &c. But these methods are now generally abandoned. Mr. Stodart, a very ingenious and scientific cutler in London, says, (as Mr. Nicholson informs us, *Journal*, vol. iv. 4to.) that one of his workmen makes up his charcoal fire with shavings of leather, finding that this is effectual in preventing the tools from cracking in the process of hardening; and he says, that he has found no advantage from the use of salt in the water.

To harden and temper English, Flemish, and Swedish steel, you must give them a pretty high heat; then suddenly quench them in water to make them hard; but Spanish and Venetian steel will need only a blood-red heat before they be quenched.

In consequence of this operation, all the qualities of steel are changed; so that from being very ductile and soft, it becomes so hard and stiff, that it is no longer capable of being cut by the file, but is itself capable of cutting or piercing very hard bodies, and that it does not yield to the hammer, but may be sooner broken in pieces than extended. It becomes also sonorous, brittle, very elastic, and capable of acquiring the most beautiful polish. This hardness and ductility of steel may be diversified by varying the temper.

The hotter the steel is when tempered, and the colder the water into which it is plunged, the greater hardness it acquires, but at the same time it becomes so much more brittle. The coldness of the water may be increased by dissolving salts in it: observing that water is always colder while the salts continue dissolving; and that the steel will cool sooner by being stirred about or placed in a stream, so as to come in contact with water not already made warm. On the contrary, the less hot the steel is when tempered, and the hotter the water is in which it is tempered, the less hard it becomes, and also the greater ductility it retains: and the proper degree of heat is always relative to the use for which the tools made of the steel are intended.

If the steel be too hard or brittle for an edged tool, &c. let it down by rubbing a piece of grindstone or whetstone hard upon the work, to take off the black scurf: then brighten, or heat it in the fire: and as it grows hotter, you will see the colour change by degrees, in the manner and by the gradations stated under the article *CUTLERY*.

Saw-makers temper their tools by rubbing them over with suet or other grease, and then heating them gradually till the temperature of each tool is sufficiently raised to set fire to the grease of itself and occasion it to blaze. They are thought to acquire in this mode of treatment a temper equal to that which would be obtained by heating them in the usual way, till they became of a deep blue. This operation, which is practised at Sheffield, is called "blazing." For the method of tempering files, in which the great desideratum is to blend tenacity with hardness, see *FILE*.

In the year 1789, Mr. David Hartley took out a patent for a method of tempering steel by the aid of a pyrometer or thermometer applied near to the surface of the article, and at the same time recommended the use of heated oil, in which (he says) many dozens of razors or other tools might be tempered at once with the utmost facility, and the various degrees of heat necessary for different purposes might speedily be determined by experiment. (See Nicholson's *Journal*, vol. i. 4to.) An improvement of this principle has been since suggested by Mr. Parkes (*Chem. Ess.* vol. iv.) by providing a bath of oil or of some kind of fusible metal for the tempering of every species of edged tool, which contrivance would, in his opinion, give to this operation a greater degree of certainty, than has ever been experienced by those who have conducted such manufactories. See *TILTING*.

Steel is usually fold tempered, because in many manufactures, the custom is to temper it as soon as it is made, probably that the purchasers of it may be better able to judge of its quality. When this steel is to be used, it must be untempered by heating it more or less, and letting it

cool slowly, that it may be extended, filed, and receive the necessary form : after which every workman tempers it again in his own way.

M. Berthoud, in his treatise on marine clocks, recommends hardening the steel-balance wheel, by daubing it over with foot (of wood) moistened with urine, putting it into a small box of thin iron-plate, and covering it over with the same composition. This box with its contents is to be heated to a blood-red, and then the wheel taken out suddenly and quenched.

Mr. Harrison and M. Berthoud seem to agree upon the whole, that the balance-spring of time-pieces should be hardened and tempered after it has been coiled up in its proper form ; and not tempered first and coiled up afterwards, as is the practice in making the main-spring. Some curious workmen, in order to equally temper small steel instruments, employ melted lead as an intermedium. A plate of iron floats upon the melted lead, and receives from it,

TEMPERING

in all its parts, an equal heat : the pieces of steel laid upon this plate, acquire all at once the same degree of heat, and are at once quenched in water ; the blue or other colours, which they successively assume, affording sure marks of the proper points of heat at which they are to be quenched, according to the different degrees of hardness required in them. Lewis's Com. Phil. Techn. p. 32.

For the method of tempering steel bars for artificial magnets, practised by Mr. Canton, see *Artificial MAGNET*.

The ancients appear to some to have had a better method of tempering than any of the moderns are acquainted with ; witness their works in porphyry ; a stone so hard, that scarcely any of our tools make any impression upon it.

TEMPERING of *Land*, in *Agriculture*, a term signifying the preparing it for a crop, especially of wheat. It is a term in much use in Norfolk. It implies all the various operations that may be undertaken in this intention.

Test and Testing

TEST, in *Metallurgy*, is a vessel of the nature of a coppel, used for large quantities of metals at once, and formed of the same materials.

The coppels, or small vessels, serve for operations of this kind, when small quantities only are concerned; but when larger are worked on, vessels of a larger size and coarser texture are employed, which are distinguished by the name of *tests*.

These are usually a foot and half broad, and are made of wood-ashes, not prepared with so much care as for coppel-making, and mixed with finely powdered brick-dust; these are made into the proper shape, either by means of a shallow vessel, made of crucible earth, or cast-iron, of proper dimensions, or only an iron ring, or hoop, with three bars arched downwards across the bottom, about two inches deep, and of different widths, from three or four inches to fifteen or more, according to the quantity of metal to be tested at once.

To make them in the first manner, an earthen vessel is to be procured, not glazed within, and by its depth and breadth proportioned to the quantity of metal to be worked; the inside of this vessel is to be well moistened with fair water, that the ashes to be put into it may adhere the better. Put into this vessel, thus prepared, the ashes and brick-dust before-mentioned, and first moistened either with water alone, or with water with a little white of an egg mixed in it; let the quantity of this be so much as will half fill the vessel, then press the mass with a wooden indented pestle, or, if not for a very large test, with a wooden cylinder, only of an inch thick: when thus pressed down add fresh ashes, and press them a second time, as in the making of coppels, and repeat this addition of fresh ashes till the earthen vessel be nearly full; then remove the superfluous ashes with an iron ruler, and let the inequalities remaining at the border be smoothed with a wooden or glass ball rolled round about. This done, you are to cut the cavity with a bowed iron, that you may have a broad spherical segment, not very deep; and lastly, by means of a sieve, strew this cavity carefully and regularly over with dry ashes of bones of animals, ground extremely fine, and squeeze these hard in, by the rotation of the wooden or glass ball. Thus you have a test finished, which, together with its earthen pot, must be set in a dry

warm place.

To make the tests in the other manner, or by means of an iron ring; let a ring of that metal be filled with ashes mixed with brick-dust, and moistened as before mentioned, in such manner that they may rise considerably above the ring; then press them strongly either with your hands, or with an indented pestle, and afterwards, with gentle blows of a rammer, press the ashes from the circumference toward the centre, in a spiral line, and that in such manner, that, after having been sufficiently pressed, they may be a small matter higher than the brink of the ring. If there are now any vacancies in the mass, empty the ring, and fill it again with more ashes; for if you should attempt to fill up these by adding, were it but ever so little, ashes, the second, or additional quantities, will never cohere so firmly with the first, but that they may probably separate in the operation.

This done, turn the ring upside down, and on the other side, or bottom, take out the ashes to the quantity of one-third part of the depth of the ring, and again fill the vacuity with the same ashes, in such a manner that there may remain no sensible cavity,

When the mass is thus prepared, cut out a cavity in the larger surface of the ring, with a bowed iron, as in the former method.

The Germans have, beside these, another kind of tests, which they call *treibscherven*. These are a sort of vessels which resist the most violent fire, and are so extremely compact, that they sometimes will retain not only melted metals, but even the glass of lead itself.

The figure and size of these vessels may be the same with that of the coppel, but they are usually made larger; and the great difference of these tests from coppels, and from the ordinary tests, which are indeed only a kind of large and coarse coppels, is, that the matter of these is more compact and coherent.

The matter for making these tests is thus prepared: take of the purest and finest clay a sufficient quantity, make it into balls, and dry them either in the air, or on the fire; when dried, beat them to powder in a mortar, and pour on the powder a great quantity of warm water; let this mixture rest a while, and when the clay has subsided, pour off

TESTING, in *Metallurgy*, denotes the operation of refining large quantities of gold and silver, by means of lead, in the vessel called a *teff*. This operation is performed by the destruction, vitrification, and scorification of all the extraneous and destructible metallic substances with which those noble metals are alloyed. It consists in adding to the alloyed gold and silver, a certain quantity of lead, and in exposing afterwards this mass to the action of the fire. The lead, by increasing the proportion of imperfect metals, prevents them from being so well covered and protected by the perfect metals; by uniting with these, it communicates to them a property it has of losing very easily a great part of its inflammable principle; and lastly, by its vitrifying and fusing property, which it exercises with all its force upon the calcined and naturally refractory parts of the other metals, it facilitates and accelerates the fusion, the scorification, and separation of these metals. The lead, which in this operation is purified, and scorifies along with it the imperfect metals, separates from the metallic mass with which it is then incapable of remaining united: it floats upon the surface of the melted mass; because by losing part of its phlogiston, (according to the former language of chemists,) it loses also part of its specific gravity, and lastly it vitrifies. The removal of the vitrified matter in the process is procured either by the nature of the vessel in which the melted matter is contained, and which, being porous, absorbs and imbibes the scorified matter as fast as it is formed; or by a channel cut in the edge of the vessel through which the matter flows out.

The process of testing is generally performed in the same manner as that of cupellation. See **ASSAYING** and **COPPELLING**.

But when great quantities of base metal are to be worked off from a little gold, recourse is had to a more expeditious method, that of testing before the bellows. An oval test is placed in a cavity, made in a hearth of a convenient height, and some moistened sand or ashes pressed round it to keep it steady: the nose of a bellows is directed along its surface, in such a manner, that if ashes are sprinkled in the cavity of the test, the bellows may blow them completely out; some have an iron plate fixed before the bellows, to direct the blast downwards. To keep the surface of the test from being injured in putting in the metal, some cloths or pieces of paper are interposed. The fuel consists of billets of barked oak, laid on the sides of the test, with others laid cross-wise on these: the bellows impels the flame on the metal, clears the surface of ashes or sparks of coal, hastens the scorification of the lead, and blows off the scoria, as fast as it is formed, to one end of the test, where it runs out through a notch made for that purpose. About two-thirds of the scorified lead may be thus collected; the rest being partly absorbed by the test, and partly dissipated by the action of the bellows. Care must be taken not to urge the blast too strongly, lest some portion of the gold should be carried away by the fumes impetuously forced off from the lead, and some minute particles of it entangled and blown off with the scoriæ. Macquer's Chem. Dict. Art. *Refining*. Lewis's Ph. Techn. p. 146.

The water which swims at top; and let this washing be so often repeated, that all the most minute lumps of the clay be broken, and whatever salt it contains perfectly washed out: then add to this fine clay, of the purest sand, of powder of calcined flints, ground, and well washed, of faulty but clean Hessian crucibles, or of any incombustible stones ground very fine, such a quantity as will render the mass thick, and hardly adhering to the hands in kneading it, or pliant when rolled into a thin lamina.

This is the matter for making this sort of tests; but, before any quantity of the vessels be made of this earth, it will

be prudent first to finish a single one, and try it, by putting on it a quantity of glass of lead, and exposing it for an hour or more to the strongest fire; by this trial you will be certain whether or not the mass is capable of making vessels that will resist both the fire and the glass of lead; and by no other means but this trial is it possible to determine the due proportion of the mixture of the ingredients for this use, on account of the variety of the clays. Nature in some places affords a clay so well tempered, that it is extremely proper for the making of tests without any preparation, or without the admixture of any other matter. Sometimes this only requires a simple washing, but commonly it is necessary to make it into balls, and powder or wash them as before directed.

On the trial of a test made of this, or the former mixed clay, if it runs into glass, you must add to it of the powder of stones, especially such as best resist the fire. Great care is to be taken not to add too much powdered chalk to these compositions, since if the matter is tempered with that alone, the tests will indeed resist the fire very well, but being too porous, they will yield a passage to litharge, which will soften them to such a degree, that they will either fall asunder of themselves, or be totally crushed when taken hold of with the tongs.

These vessels are to be made in the following manner: rub over the sides and bottom of a small mortar, and also its pestle, with oil, or with the fat of bacon; fill it two-thirds full of prepared clay, then make a slight impression with your fingers in the middle of the clay; then place the bottom of the pestle there, and force it down with blows of a hammer, the stronger the better. When thus properly hollowed, take it out of the mortar, and pare its edges, and dry it, as the coppels are dried, in the air, in a dry warm place.

Tests thus prepared may be used as soon as dry, unless for salts or litharge; but these bodies, when melted in vessels not first baked or hardened in the fire, always make their way through them.

Some of the German writers also recommend, both for tests and coppels, a sort of friable opaque stone, called white spath, which appears to be a species of gypsum, or of the stones from which plaster of Paris is prepared. The spath is directed to be calcined with a gentle fire, in a covered vessel, till the slight crackling, which happens at first, has ceased, and the stone has fallen in part into powder; the whole is then reduced into subtle powder, which is passed through a fine sieve, and moistened with so much of a weak solution of green vitriol, as is sufficient for making it hold together. Gellert, however, finds, that if the stone is of the proper kind, which can be known only by trials, calcination is not necessary. These tests are liable to soften or fall asunder in the fire, which inconvenience may be remedied, according to Scheffer, by mixing with the uncalcined stones somewhat less than equal its weight, as eight-ninths of such as had been already used and penetrated by the scoria of the lead, taking that part of the old test which appears of a green-grey colour, and rejecting the red crust on the top. But from his account it appears, that these tests are less durable than those made of the ashes of bones, though much superior to those of wood-ashes. Vegetable ashes, which stand pretty well the testing of silver, can scarcely bear any great quantity of gold, which requires a considerably stronger fire than the other; but bone-ashes, says Dr. Lewis, answer so effectually, and are among us so easily procured, that it is unnecessary for the refiner to search for any other materials. Cramer's Art of Assaying, p. 60. 62. Lewis's Com. Ph. Tech. p. 144.

Tilt-hammer

The tilt-hammer is distinguished from the lift-hammer, or forge-hammer, by the manner in which it is lifted up by the cogs of a wheel which is turned by the mill.

The forge-hammer is mounted on a centre of motion at the extremity of the haft or helve of the hammer opposite to the head of the hammer, and the cogs of the wheel operate beneath the helve near the head, to lift or toss up the hammer against a strong wooden spring called the rabbit, which is firmly fixed over the head of the hammer. This spring reflects the hammer down upon the anvil with greater force and smartness than the hammer would descend by the action of gravity alone. A lift forge-hammer is described under the article IRON. See *Plate IV. Iron Manufacture.*

The tilt-hammer is poised on pivots or a centre of motion, which is about the middle of the length of the helve, or sometimes at two-thirds from the head. The cogs of the wheel are made to act on the tail of the helve beyond the centre of motion, and they press down the end of the tail, and thus cause a correspondent elevation of the head of the hammer. Sometimes the spring is placed over the head of the hammer, the same as a lift-hammer; but more commonly, the tail of the hammer is made to strike against a fixed floor; and when the head of the hammer is thrown up suddenly, the momentum given to it causes the head to rise up after the tail strikes the floor, and thus bends the helve, which by its elasticity causes the head of the hammer to descend smartly upon the anvil.

The *tilt-mills* in the neighbourhood of Sheffield are very simple: they are worked by a small water-wheel, upon the axis of which is a wheel with a great number of cogs, fixed in its circumference. These successively depress the tail of the hammer, and raise its head: the hammer falls by its own weight, aided by the spring of the helve, upon the hot metal. The size of the water-wheel, and the number of cogs in the wheel, are adapted to produce from three hundred to four hundred strokes *per* minute.

This great number requires the water-wheel to move with a velocity which is inconsistent with the best mode of applying the fall of water, because it is well known that water, as well as any other heavy body, can only descend with a certain speed. If, therefore, the floats of the wheel are required to turn with a great rapidity, it is evident the proportion of work the wheel will perform, will be but small in proportion to the quantity of water expended. For this reason, it is found to be a great improvement in tilt-mills to add cog-wheels which will give the hammers a sufficient velocity, while the water-wheel turns at such a rate as is found to produce the greatest power from a given quantity of water.

A capital mill of this kind is delineated in *Plate VIII. Iron Manufacture.* It was made at the Carron iron-works in Scotland, after designs of the celebrated Mr. Smeaton. It is adapted for forging iron into bars, and has three tilt-hammers of different powers for different kinds of work. These hammers are not made to strike so quick as is usual in the Sheffield mills for the tilting and drawing out steel bars; but by giving a greater number of cogs to the wheels, the requisite rapidity may be obtained without increasing the speed of the water-wheel. A capital mill was built at Sheffield about six years ago, which is on Mr. Smeaton's plan, except in the proportions of the wheels, and its performance is superior to any of the other tilt-mills.

AA, in the plan *fig. 1.* are the walls of the building; BB the great water-wheel, which is of the kind called a breast-wheel. (See *WATER-Wheel.*) It is 18 feet diameter

and 5 feet broad. The total descent of the water which actuates it is 7 feet 2 inches, and it falls upon the float-boards rather below the centre of the wheel, being retained against the floats by what is called the breasting, that is, a sweep or curved wall of masonry, which is accurately adapted to the float-boards of the wheel, and as close to them as is possible, to avoid touching.

The axis C of the water-wheel is carried through the wall A, and on the extreme end of it is a large iron wheel D, of 90 wooden teeth, 9 feet 6 inches diameter. This turns a pinion E of 30 teeth, and 3 feet 2 inches diameter. The pinion is fixed on one end of a cast-iron axis GG, which is made very large, for strength, and hollow within, like a pipe. The gudgeons *b* and G are fixed into it at each end, and upon these gudgeons it revolves. FF is a cast-iron fly-wheel, fixed on the axis close to the pinion; it is 12 feet diameter, and the rim 6 inches by 5. The weight is very considerable, and gives it a momentum to regulate the motion of the whole mill, and equalize all irregularities which arise from the successive actions of the mill to raise the three hammers, L, M, and N.

Each hammer has a separate cog-wheel, K, I, and H, to give it motion, which is effected by the cogs of these wheels acting upon the tails of the hammers and pressing them down. This is explained by the elevation *fig. 2.* where *e* is the iron head of the hammer, *f* its centre of motion, and *d* the tail or extreme end, upon which the cogs of the wheel act, and which is plated with iron on the upper side, to prevent it from wearing.

P is the anvil-block, which must be placed on a very firm foundation, to resist the incessant shocks to which it is subjected: the centre, *f*, or axis of the hammer, is supported in a cast-iron frame, *gb*, called the hirst. When the cogs of the wheel strike the tail of the hammer suddenly down, and raise the head, the lower side of the tail of the hammer strikes upon a support *n*, which acts to stop the ascent of the head of the hammer *e*, when it arrives at the desired height; but as the hammer is thrown up with a considerable velocity as well as force, the effort of the head *e* to continue its motion, after the tail strikes the support *n*, acts to bend the helve L of the hammer, and the elasticity of the helve recoils the hammer down upon the anvil with a redoubled force and velocity to that which it would acquire from the action of gravity alone.

To obtain this action of recoil, the hirst *gb* must be held down as firmly as possible; and for this purpose, four strong iron bolts are carried down from the four angles of the bottom plate *b*, and made fast to the solid basis of stone RR, upon which the whole rests: upon this basis are placed four layers of timbers, *i, k, l, m*, which are laid one upon another, and the timbers of each layer are laid crossways over the others. Each layer consists of several pieces laid side by side, and they are slightly treenailed together, to form a platform. Each platform is rather less than that upon which it rests, so as to form a pillar of solid timber; on the top of which the hirst-frame *gb* is placed, and firmly held down by the four bolts, which descend through all the platforms, and have secure fastenings in the solid masonry beneath.

The stop *n* is supported by a similar pillar, but smaller, and composed of three layers: the upper piece *n*, which is seen crossways in *fig. 2.* is about three feet long, and the under side is hollowed, so that the piece bears only upon the two ends, leaving a vacancy beneath it, which occasions

it to bend or spring every time the tail *d* of the hammer strikes upon it, and this aids the recoiling action very much.

The axis on which the hammer moves is formed by a ring of cast-iron, through which the helve of the hammer is put, and held fast by wedging round it. The ring has a projecting trunnion on each side, ending in an obtuse conical point, which is received in a socket firmly fixed in the hilt-frame *g b* by screws and wedges, one of which is seen at *r*. These two sockets are thus capable of adjustment, so as to make the hammer face fall flat upon the anvil. The three wheels K, I, H, are of different sizes and numbers of cogs to produce that velocity in each hammer which is best adapted for the work it is to perform: thus, the wheel K for the great hammer has eight cogs, and therefore produces eight blows of the hammer for each revolution of the fly-wheel; the wheel I for the middle hammer has twelve cogs; and the wheel H for the small hammer sixteen; the latter will therefore make two strokes for every one of the great hammer. In fixing the three wheels upon the great shaft G H, care is taken that they shall produce the blows of the different hammers in a regular succession, and equalize as much as possible the force which the water-wheel must exert. The wheels are fixed upon the shaft by means of a wedging of hard wood, driven in all round; the wood, being capable of yielding a little to the shocks occasioned by the cogs meeting the tails of the hammers, renders the concussions less violent.

The following are the principal dimensions:

The head of the great hammer, P, weighs $3\frac{1}{4}$ cwt., and it is intended to make 150 blows *per minute*: it is lifted 17 inches from the anvil at every blow.

The middle hammer, M, is 2 cwt., and makes 225 blows *per minute*: it is lifted 14 inches each time.

The small hammer, N, weighs $1\frac{1}{2}$ cwt., and makes 300 blows *per minute*: it is lifted only 12 inches.

To produce these velocities, the great axis G must make $18\frac{1}{2}$ turns *per minute*; and the cog-wheels E and D, being in the proportion of one to three, the water-wheel must make $6\frac{1}{2}$ revolutions *per minute*; the water-wheel being 18 feet diameter, its circumference will be $18 \times 3.1416 = 56.54$, or $56\frac{1}{2}$ feet: this multiplied by 6.25 is about 353 feet motion *per minute*, or divided by 60 = 5.9 feet motion *per second* for the circumference of the water-wheel.

The tilt-mills employed in the manufacture of steel, do not have the great hammer P, but the largest they use is about the size of that at M, and is adapted for welding faggots of steel to make shear steel: the other two hammers are about the size of N, and are made to work much quicker, *viz.* from 350 to 400 blows *per minute*. This is very easily accomplished by making the wheels E and F as 1 to 4, instead of 1 to 3, as shewn in the drawing.

TILTH, in *Agriculture*, a term used to signify the condition of the earth or soil after the land has been ploughed and broken down by the harrow or other tool of the same kind; or the state and circumstances of the ground in regard to tillage, or heart, as relating to manure. Thus we have a *good* and *bad* tilth, as well as land *in* and *out* of tilth, in works on agriculture.

TILTIL, in *Geography*, a town of Chili; 30 miles S.E. of Valparayso.

TILTING of Steel, the process by which blistered steel, or steel in the raw state, is rendered ductile and fit for the purposes of various manufactures. Tilting consists in hammering or forging the steel by a large hammer called a *tilt*. See **TILT-Hammer**.

Steel is formed by two processes: one in which it is made at once from pig or crude iron in the finery, nearly in

the same manner as making bar-iron: this is called natural steel. In the second process, malleable iron, in bars, is imbedded in charcoal or other carbonaceous matter, and exposed to a considerable heat, till the carbon is thought to have penetrated sufficiently into the iron to have changed it into steel. This is called converting the iron by cementation with charcoal; and the furnace in which the operation is performed is called a converting furnace.

The object of this process of cementation, is to impregnate the iron with a certain quantity of carbon, to be derived from the charcoal: like many other simple operations, it requires great care and nicety to perform it properly, when put in practice on a large scale. The iron must be exposed to the action of an intense heat in contact with carbon (but defended from the access of oxygen), until the iron imbibes a portion of carbon and becomes steel.

The quantity of carbon which must be combined with iron to produce steel, admits of considerable latitude, and the qualities of the steel vary in the same proportion: with too little carbon, steel will be soft; and not sufficiently hard when it has been suddenly cooled by plunging in water. It has a rough and somewhat fibrous fracture, and in general may be said to possess many of the qualities of malleable iron. On the other hand, in proportion as the quantity of carbon is diminished, an over-cemented steel, containing an excess of carbon, is brittle, easily fusible, excessively hard after being suddenly cooled, and is liable to crack on the sudden change of temperature from hot to cold. All these properties are an approach to crude iron.

The received opinion respecting steel and the best cast-iron is, that they have the same constituent parts, but in different proportions; the former containing a smaller proportion of carbon than the latter. All the crude or cast-iron of commerce contains oxygen in greater or less proportion, but the best steel is supposed to be nearly free from this. Mr. David Muirhead, whose great practical and theoretical knowledge entitles his opinion to the greatest respect, supposes that the carbon contained in cast-iron and in steel, exists in very different states; and that steel is a combination of iron with pure carbon, similar to the diamond, but that crude iron, is iron containing the oxyd of carbon, which is charcoal. This opinion he founded upon the result of a very numerous series of experiments, many of which he communicated to the Philosophical Magazine, vol. xiii. He found that a piece of Swedish bar-iron, weighing 885 grains, introduced into a Stourbridge clay crucible, and half its weight (442 grains) of charcoal well prepared; a clay cover, fitting exactly, being placed on, and the whole exposed to a moderate heat for half an hour; that the result was, a perfect button of super-carbonated crude iron, weighing 928 grains, which therefore had gained $\frac{1}{19}$ th on its original weight; while the charcoal, which remained in the crucible in an intensely black state, weighed 290 grains, having lost $\frac{34.4}{100}$ *per cent.* of its original weight.

In a second experiment, made in a similar manner, but with only a quarter of the charcoal, the iron gained $\frac{1}{19.75}$ of its ori-

ginal weight, and the loss in charcoal was $\frac{45}{100}$ *per cent.*: the metal was richly carbonated. When one-sixth of charcoal was used, the iron produced, resembled the produce of No. 1. and 2. of the crude iron of commerce; its weight was increased $\frac{1}{20.4}$; and 57 *per cent.* of the charcoal disappeared in the process.

With one-eighth of charcoal, the iron gained $\frac{1}{22}$ of its

original weight ; and the weight of the charcoal which disappeared was $67\frac{7}{8}$ per cent. The metallic button was very highly carbonated, and apparently formed an entire mass of carburet.

One-ninth of charcoal produced a super-carbonated button of crude iron, rather inferior to the preceding in point of carbonization : its surface was smooth, and of a dull lead-colour, entirely free from the usual shining specks of carburet, which very rich crude iron contains upon its surface. It had gained equal to $\frac{1}{8}$ th in weight by the fusion ; and the loss in charcoal was 80 per cent.

When treated in the same manner with $\frac{1}{2}$ th of its weight of charcoal, the iron gained weight equal to $\frac{1}{7}$ parts : and 83.5 per cent. of the charcoal disappeared in the process. The metallic button possessed a uniformly smooth surface, partially covered with carburet.

One-fifteenth part of charcoal, exposed with the iron to a heat sufficient to melt it, was all lost ; the metal gained $\frac{1}{6}$ th in weight, which was exactly half the weight of charcoal lost. The surface of the button was not carbonated, as the foregoing experiments : the colour was blueish-black, smooth in the centre, but a little oxydated towards the edges. The fracture was that of close dark-grey crude iron ; the crystals much closer and more minute than in the preceding experiments. Its quality was such as manufacturers term No. 2. grey melting pig-iron.

When only $\frac{1}{6}$ th part of charcoal was employed, none of which remained after the fusion, the iron gained $\frac{1}{4}$ parts in weight : a small portion of amber-coloured glass was found round the edges of the button. The fracture of the metal was smooth silvery-white, occasionally studded with carbonaceous specks in form of small grains : it exactly resembled mottled pig-iron.

With $\frac{1}{3}$ th part of charcoal, the metal gained $\frac{1}{3}$ parts in weight, the whole of the charcoal disappearing. The upper surface of the button was smooth, but the under considerably pitted. The concaves were chequered with the rude crystallization peculiar to cast-iron. Its fracture was bright silvery-white, destitute of grain, and exhibiting a very perfect freaky crystallization slightly radiated : its resemblance was strikingly similar to that of highly-blown crude iron, prepared in the finery for making malleable iron.

A piece of Swedish iron was placed in $\frac{1}{3}$ th its weight of charcoal : the fusion of the mixture produced a metallic button weighing $\frac{1}{7}$ parts more than the iron employed, which increase is not quite a quarter of the loss in charcoal, which wholly disappeared in the experiment. The upper surface of the button was smooth without configuration, but the under surface was uneven, and covered with minute but perfect crystallization : its fracture was blueish silvery-white, composed of flat dazzling crystals, proceeding in lines from a centre to the edges of the button. Here it was evident, that from the small proportion of carbon combined with the iron, it was found to assume the earliest stage of granulation approaching to the state of steel. The brilliant concretions observable in the surface of the button were too indistinct and flat for steel capable of bearing the hammer.

When the proportion of the charcoal was reduced to $\frac{1}{8}$ th of the iron, its consequent increase was but $\frac{1}{8}$ th part. The upper surface of the button was smooth, with a faint impression of a chequered crystallization : the under surface possessed some large pits similarly though more perfectly crystallized ; the fracture was one shade of blue beyond the last experiment. A regular granulated surface, composed of flat oblong crystals, was observable, still too indistinct and too much on edge for workable steel.

With only $\frac{1}{16}$ th of the weight of charcoal, the button was deficient $\frac{1}{16}$ th part of its weight originally used, yet

the whole of the charcoal was lost. The surfaces of this button were uniformly smooth ; the fracture dense, and displaying a grain peculiar to highly saturated blistered steel. When put under the hammer with a low red heat, it withstood a few blows, but afterwards parted.

Charcoal $\frac{1}{16}$: the metallic button weighed $\frac{1}{31\frac{6}{10}}$ less than

the iron employed. Its surface was wavy and crystallized : the under surface was rough, and contained one large pit accurately crystallized : the fracture was regularly granulated, small but distinct, and of a light blueish colour. The crystals, though distinct, were not so prominent as those of easy drawing cast-steel ; it however hammered with the usual degree of caution necessary in the working of cast-steel. The bar of steel formed from the button was very proper for file-making, and other purposes requiring highly converted steel.

The proportion was reduced to $\frac{1}{16}$ th part the weight of iron : the produce was $\frac{1}{22\frac{1}{10}}$ less than the original weight

of iron. The surface of the button was smooth, without crystals : the under surface rough, and possessed of one large pit in the centre, faintly marked with the usual crystalline appearance. The fracture presented regular light-blue grains, distinct and more prominent than in the last experiment. One half of this button was drawn into a neat square bar, and proved excellent steel. One end of it, being loose and shaled, welded tolerably well, and hardened afterwards with a low heat. From its quality, it seemed adapted for manufacturing penknives, razors, &c. possessing neither the extremes of hardness nor softness.

Mr. Musket continued this series of experiments till the proportion of charcoal became so small as $\frac{1}{16}$ th part ; and he gives the following conclusions, deduced from the results.

	Parts by Weight.
Iron semi-steelified is made with charcoal	135
Soft cast-steel, capable of welding, with	175
Cast-steel for common purposes, with	755
Cast-steel requiring more hardness, with	95
Steel capable of standing a few blows but quite unfit for drawing,	15
The first approach to a steely granulated fracture, is from	30 to 115
White cast-iron	15
Mottled crude iron	15
Carbonated crude iron	15
Super-carbonated crude iron	15, or

when any greater quantity is combined with it.

In the above experiments it will be seen, that when more than $\frac{1}{8}$ th part of charcoal is employed, the weight of the produce is increased ; but when less than $\frac{1}{8}$ th part is used, a loss is experienced proportioned to the diminution of the carbon. The increase of weight in the iron is by no means equal to the loss in the charcoal, never exceeding the half thereof ; but this is accounted for in other experiments made by Mr. Musket, where charcoal was found to be transmitted through close crucibles in a high degree of heat.

The French chemists made a direct experiment to prove that the diamond is really carbon in a crystallized state. By inclosing a small diamond in a piece of malleable iron, and melting this in a close crucible, it was found to be converted into steel, and the diamond had disappeared.



The manufacture of *natural steel* is carried on in Germany, and Swedenborgius gives us the following account of the method used in Dalecarlia for making steel from cast-iron,


The ore from which the crude iron to be converted into steel is obtained, is of a good kind; it is black, friable, and composed of many small grains: it produces very tough iron. The conversion into steel is made upon a forge-hearth, something smaller than that commonly used for converting cast-iron into malleable iron: the sides and bottom are made of cast-iron; the tuire is placed with very little inclination on one of the side-plates; the breadth of the fire-place is fourteen inches, its length is greater; the lower part of the tuire is six inches and a half above the bottom: in the interior part of the fire-place, there is an oblong opening for the flowing of the superfluous scoria.

The workmen first put scoria on the bottom, then charcoal and powder of charcoal, and upon these the cast-iron, run or cut into small pieces. They cover the iron with more charcoal, and excite the fire. When the pieces of iron are of a red white, and before they begin to melt, they stop the bellows, and carry the mass under a large hammer, where they break it into pieces of three or four pounds each: the pieces are again brought to the hearth, and laid within reach of the workman, who plunges some of them into the fire and covers them with coal. The bellows are made to blow slowly till the iron is liquefied, when the fire is increased; and when the fusion has been long enough continued, the scoria is allowed to flow out, and at that time the iron hardens. The workman adds more of the piece of crude iron, which he treats in the same manner, and so on a third and fourth time, till he obtains a mass of steel of about a hundred pounds, which is generally done in about four hours. This mass is carried to the hammer, where it is forged and cut into four pieces, which are further beat into square bars four or five feet long. When the steel is thus forged, it is thrown into water, that it may be easily broken, for it is yet crude and coarse-grained. The steel is then broken in pieces, and carried to another hearth, similar to the former. These pieces are laid regularly in the fire-place, first two parallel, upon which seven or eight others are placed across; then a third row across the second in such a manner, that there is a space left between those of the same row: the whole is then covered with charcoal, and the fire is excited. In about half or three quarters of an hour the pieces are made hot enough, and are then taken from the fire one by one, to the hammer, to be forged into little bars from half a foot to two feet long, and while hot, are thrown into water to be hardened. Of these pieces, sixteen or twenty are put together, so as to make a bundle, which is heated and welded, and afterwards forged into bars four inches thick, which are then broken into pieces of convenient length for use.



Converting of Steel by Cementation with Charcoal.—The quality of steel is intimately connected with that of the iron from which it is converted, and the iron made in Sweden is esteemed the best for the purposes of cementation. This process is almost wholly in the hands of the English, who pay a higher price for the iron, and by that means secure nearly all the iron of Roslagia, which is the best iron of Sweden.

The best marks of Swedish iron are: that called the hoop L, which is denoted by a circle, with an L in the centre;

thus,  the GL; thus, : the double bullets

thus, . The iron of these three marks bears nearly the same price, which is sometimes as high as 40*l.* per ton.

There are also the Swedish marks; as P L,  the hoop

S, : and the gridiron, ; which are worth

few pounds per ton less than the former; viz. from 34*l.* to 38*l.*, when the best marks are 40*l.*

The Russian marks are, first, that called the CCND: the mark is six Russian letters, CHEHPB, worth about 37*l.* per ton, when the others are at 40*l.*: and the P S I, which is marked by the Russian letters P S I, is so inferior, as to sell for only 26*l.* or 27*l.*

It is to be lamented that, in the present state of our iron manufacture, we are unable to produce malleable iron which is equally fit for converting into steel with the Russian and Swedish iron. The general opinion upon this deficiency is, that it arises from some superiority in the foreign ores of iron, but more immediately from the circumstance of their using charcoal of wood instead of the coke of pit-coal in smelting or reviving them; and some of our manufacturers do not hesitate to assert, that they can make iron with charcoal equal to the foreign in quality; but that in respect to price, the circumstances of this country will not allow them to cope with those countries, where the destruction of wood is in some measure considered as beneficial, by clearing the land for the operations of husbandry.

The Swedish and Russian iron is imported into this country by iron merchants in immense quantities together, this trade being in the hands of a few individuals: by them it is retailed in smaller portions to the converters, whose furnaces are chiefly about Sheffield and at Newcastle, who, after cementation, dispose of the greater part of it to the manufacturers of steel goods in the state of blistered bars. Its value is estimated by the Swedish or Russian marks of iron, which still remain upon the bars. The manufacturers send their bars to the tilt-mills, where they are made into common steel and shear or German steel, or they melt it to form cast-steel.

The conversion of iron into steel is performed in a furnace, hence called a converting furnace. The external building is a large and tall cone, similar to a glass-house, within which, one or two large crucibles, called pots, are placed, and surrounded by flues in a manner best calculated to communicate a constant and regular heat to every part of them. In these pots the iron bars are placed, being stratified in pulverized charcoal, and the pots are covered over with sand to exclude the external air.

A more perfect idea of the converting furnace will be had by referring to *Plate VII. of Iron Manufacture*, which contains a horizontal plan and two vertical sections of one of the furnaces used in the neighbourhood of Sheffield, with two pots for containing the iron. In all the figures, the same letters of reference denote the same parts. CC is the external cone, built of brick or stone work; its diameter at the base varies in different furnaces, according to the size of the pots it contains: its extreme height from the ground to its vertex should not be less than forty or fifty feet to cause a proper draught. To create a sufficient heat for the process, the top of the cone usually terminates with a cylindric chimney of some feet in height. The conical form of the external building is by no means essential; any form will operate in the same manner, if it is of a proper height: some are in practice built nearly in the shape of the small end of an egg, with a round chimney upon the top. The lower part of the cone is built square or octangular, as is the plan of *fig. 3*. The sides are carried up until they meet the cone, giving the furnace the appearance of a cone cut to a square or octangular prism at its base, and exhibiting the parabola where every side intersects the cone.

The conical building contains within it a smaller furnace,

called the vault, built of fire-brick or stone, which will withstand the action of a most intense heat, without cracking or vitrification. D D in the section is the dome of the vault, and E E its upright sides, the space between which, and the wall of the external building, is filled up with rubbish and sand. The vault, as is shewn in the plan, is always four-sided, that it may contain the pots which receive the iron bars to be converted. A B represent the two pots, built of fire-stone, each ten feet long, three feet deep, and two feet nine inches wide; the space between them is twelve inches wide; and directly beneath it is the fire-grate. The pots are supported by a number of detached courses of fire-brick, as shewn at *ee* (fig. 1.) which leave spaces between them, called flues, to conduct the flame under the pots: in the same manner, the sides of the pots are supported from the vertical walls of the vault, and from each other, by a few detached stones, (*f*, fig. 1.) placed so that they may intercept as little as possible of the heat from the contents of the pots. The adjacent sides of the pots are supported from one another by small piers of stone-work, which are also perforated, as shewn at *d* (fig. 2.) to give passage to the flame. The bottoms of the pots are built of a double course of brick-work, about six inches thick; the sides nearest together are built of a single course of stone, about five inches in thickness; and the other parts of the pots are single courses about three inches, the sides not requiring so much strength, because they have less heat and pressure to resist.

The vault has ten flues or short chimneys, F F, rising from it; two on each side, to carry off the smoke into the great cone, shewn in the plan 3, communicating with each side, and two at each end.

In the front of the furnace, at H, an aperture is made through the external building, and another corresponding in the wall of the vault: these openings form the door, at which a man enters the vault to put in or take out the iron; but when the furnace is lighted, these doors are closed by fire-bricks luted with fire-clay. Each pot has also small openings in its end, through which the ends of two or three of the bars are left projecting in such a manner, that by only removing one loose brick from the external building, the bars can be drawn out without disturbing the process, to examine the progress of the conversion from time to time: these are called the tap-holes; they should be placed in the centre of the pots, that a fair and equitable judgment may be formed from their result of the rest or its contents.

ab, in the elevation, is the fire-grate, formed of bars laid over the ash-pit I, which must have a free communication with the open air, that it may convey a current of fresh air to supply the combustion. The ash-pit should also have steps down to it, that the attendant to the furnace may get down to examine by the light, whether the fire upon the whole length of the grate is equally fierce; and if any part appear dull, he uses a long iron hook to thrust up between the bars and open a passage for the air. The fire-place is open at both ends, and has no doors. The fire-grate is laid nearly on a level with the floor of the warehouse, before the furnace, and the fireman always keeps a heap of coals piled up before the apertures at its ends, so as to close the opening. This forms a very simple and effective door; and when the furnace requires a fresh supply of fuel, a portion of the heap of coals is shoved in by a sort of hoe, and the heap renewed, to stop any air from entering into the furnace, except that which has passed upwards through the ignited fuel, and by that means contributed to the combustion.

The fire-stones that compose all those parts of the furnace which are exposed to the action of the heat, are first hewn nearly to size, and finished by grinding two surfaces together, so that they make very perfect and close joints:

when laid together, they are cemented with well-tempered fire-clay, mixed up very thin with water. The fire-clay which answers best for this purpose, is that brought from Stourbridge, in Staffordshire, and is the same of which the celebrated Stourbridge crucibles are composed; but very good fire-clay for the purpose is procured from Birkin-lane, near Chesterfield. When the furnace has been once burnt, this clay becomes equally hard with the stone, and is less liable to fly or vitrify in an intense heat, than any other known cement.

The process of charging the furnace with iron for conversion is conducted as follows. The bars of iron are first cut to the length of the pot; and for this purpose an anvil is placed at such a distance from the wall of the building, that the distance from the edge of a cold chisel wedged into the eye of the anvil, to the wall, will be just the length of the pots. One workman places the end of a bar against the wall, and lays the other end across the edge of the chisel, whilst another with a sledge-hammer strikes upon the bar till it is cut half through; then it is turned the other side upwards, and the end cut completely off. By this gauge the bars are all cut to one length, and a man enters through the door in the vault, to dispose of them in the pots: he is provided with a basket of fine pulverized charcoal, a sieve, and a shovel. An iron plate is put into the furnace, and lays over the space between the two pots to form the floor, upon which the man stands while at work. He commences his operations by sifting a layer of charcoal over the bottom of the pot, about half an inch thick, and he is careful in using the sieve to lay the charcoal of an even thickness in every part; but if it should not be carefully done, he levels it with the shovel. The workman on the outside now introduces the bars into the furnace through a hole, made by taking out a brick in the wall, just over the end of one of the pots, and the workman within deposits them upon the stratum of charcoal in the bottom of the pot, arranging them parallel to each other, and leaving an interval of about an inch between each bar. When the bottom of the pot is in this manner covered with iron bars, charcoal is again sifted upon them, and levelled with the shovel, to fill up the intermediate spaces between the bars, and to cover them about an inch thick: another layer of bars is then introduced into the furnace, placed upon the charcoal, and in its turn covered over with a stratum of charcoal; and in this manner the pot is filled to within two inches of the top. A layer of the sand which is found in the bottom of grindstone troughs, is then spread three or four inches thick upon the whole, to cover the pots up close, and prevent the access of the common air and flame. In placing the successive layers of bars in the pot, it is proper that each should be laid over the space between two of the bars in the layer beneath, because each bar will then be surrounded by a greater thickness of charcoal, than it would if they were laid directly over each other. Two or three of the bars should be left somewhat longer than the rest, and their ends should project through the tap-holes in the ends of the pots, and sand rammed round them in the holes to keep out the air.

The pots being both filled and covered up with the sand and rammed down, the holes for introducing the bars are closed by a brick or fire-stone, and luted with fire-clay. The apertures through the outer wall opposite the ends of the tap-holes are also stopped and luted. The iron plate upon which the man stood is now removed, and the doors in the vault closed up by bricks set with fire-clay; next, the opening in the external building is shut up, and the furnace is charged ready for lighting.

The furnace is kindled by lighted wood placed on the fire-grate, then a few coals are thrown in, and when well lighted, the quantity is increased; the heat thus generated rarefies the air contained in the vault and in the great cone;

and being thus rendered of less specific gravity than the external air, it rises up in the cone, and a fresh supply rushes in through the bars of the grate, to restore the equilibrium. By going through the fire, this air parts with its oxygen, and excites the combustion, and becoming heated, rises up the chimney, and causes a very strong draught of air to enter the fire.

At first kindling, the fuel is supplied in small quantities, that the heat in the furnace may be gradually increased, and not endanger the cracking of the stones: in a few hours time the quantity of fuel is increased, so as to produce the full heat, which is to be maintained as equally as possible throughout the whole process. The fuel, which is pit-coal, is introduced at both ends of the grate, through small arches in the wall, which are in a line and on a level with the fire-grate, a quantity of coals being always left before the end of the arch to stop it up, and prevent any air getting into the furnace, without passing through the grate. Part of these coals is forced into the furnace, as before mentioned, when it requires a supply of fuel, which is generally at intervals of about half an hour each. The fireman frequently examines the appearance of the under side of the fire-grate, and judges from it the state of the fire: he improves it where necessary, as before described, by thrusting a hook up between the bars to make way for the air.

The flame arising from the ignited fuel upon the grate partly proceeds upwards between the pots, and heats them by that means; it then strikes the roof of the vault, and is reverberated down upon the pots, and escapes through the six flues or chimnies in the vault. The draught also draws the flame from the grate under the pots, and round the outside and ends. The principal object in this stage of the process, is to maintain the same degree of heat in every part of the pot, that every bar may be equally converted in the same space of time. The roof of the vault must be built of very good stone (none being better than from Roches quarry, in Aslaover), to withstand the great heat exerted upon it: it is customary to build them very thin, and cover the outside with a small thickness of dry sand to keep them tight, in case of a stone cracking.

In this way the fire is kept up in as equable a manner as possible, until the iron is supposed to have imbibed a sufficient portion of carbon from the charcoal to render it fit for its intended purpose: in this circumstance, the manufacturer regulates his judgment by his experience of former processes. About the time that he supposes the conversion to be sufficiently advanced, one of the trial-bars is drawn out from the pot, and by comparing the size of the blisters raised upon its surface with another bar which is known to be sufficiently carbonated, an idea is formed of the state of the furnace, and accordingly the fire is, at the proper time, discontinued, and the furnace is suffered to cool. Some manufacturers proceed to make experiment of the trial-bar by hardening and tempering it, so as to prove to a certainty the degree of its conversion, the blisters being found in some degree fallacious; for their size depends as much upon the degree of heat to which the bar has been exposed, as upon its carbonization, and shew the rapidity with which the conversion has been carried on, rather than its actual state.

The time which the iron is required to be in the process of cementation depends upon a variety of concurring circumstances. 1. The degree of carbonization required to form a steel of the proper quality; this varies with the use the steel is to be applied to. 2. The heat it is subjected to. 3. The nature of the iron employed in the process. The combinations of these circumstances are so numerous, that nothing but long experience can determine the proper duration of the process.

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In general terms it may be observed, that a short period will produce a steel very soft and tenacious, which, when properly treated, will possess elasticity as its most striking property, and is therefore very proper for springs, wire-drawing, and other purposes requiring ductility, but without the hardness requisite for edge-tools. The period of cementation for such steel varies in different manufactories, from four to six days and nights.

Steel which requires more hardness, but at the same time sufficient tenacity to resist sudden shocks, such as the edge-tools for working wood are subject to, must be cemented a longer time. This, which is mostly tilted into shear steel, is cemented six, seven, or eight days, according to the heat and the quality of iron employed. The steel employed for fabricating tools for cutting metals and hard substances being but small in demand compared with the others, is not cemented a longer time, but is returned into the furnace at the next charge, along with a charge of iron, and cemented again with fresh charcoal: this is termed double converted steel. But for some few purposes, such as the turning and boring of cast-iron, the steel is converted three times: in this state it becomes so hard and brittle as to be totally unfit for any purpose requiring tenacity, or for any cutting edge which is less than an angle of 70 degrees, or it would be continually breaking.

The heat which is requisite for the process, must be as great as to give the iron nearly a welding heat, but if carried farther, will endanger melting the bars when the process has proceeded some time; an accident which has frequently occurred through the inattention of the fireman. It is observed by manufacturers, that the carbonization proceeds quicker when the heat is greatest, and for this reason the duration of the process varies in different furnaces, in some measure from their construction, in urging a greater heat, and this depends chiefly upon the height of the chimney, and the draught it occasions.

When the conversion is supposed to be complete, the furnace is suffered to cool, until a man can conveniently enter the furnace, to take out the bars and remaining charcoal, and prepare the furnace for a new charge. The bars which are brought out are (from being covered with blisters upon the surface) termed blistered steel.

On examination of the fracture of a blistered bar, it is found full of internal cracks, which are generally parallel to the flat side of the bar: some of them are larger than others, and extend the parts of the bar sufficiently to raise numerous protuberances or blisters upon its surface. These cracks have every appearance of being opened by the expansive force of some gas generated in the iron during the process, but what the nature of this gas is, still remains to be investigated. It seems to arise from the body of the iron itself, by the crack being within the solid substance of the bar. The fracture of the blistered steel is exceedingly irregular, of a white colour, like frosted silver, and appears like an irregular crystallization; but the facets exhibited are larger in proportion as the cementation has been longer continued, and from this reason they are larger towards the surface of the bar than in its centre.

The furnace above described is of that kind which is esteemed the best for the process, and is most generally employed in and about the neighbourhood of Sheffield in Yorkshire, where the manufacture of steel is carried on in a larger scale than in any other part of England. The furnaces used at Newcastle, which is another seat of this trade, are very similar.

The charge consists of twelve tons, each pot containing six tons of iron; and it is necessary that all the bars converted

at one process be of the same size, or the smaller ones would be thoroughly converted before the others had taken up a sufficient dose of carbon. This large quantity of a single article is more than the trade of some manufacturers will dispose of, they therefore employ smaller furnaces, which contain only eight tons, and such are generally constructed but with one pot ten feet in length, three feet broad, and two feet deep: the fire-place is directly beneath the pot, twenty inches wide, and flues are carried round it on both sides and ends: the vault and chimney of such a furnace are the same as the double pot. It is found by experience that the small furnaces consume somewhat more fuel in proportion to the quantity of iron they convert, than the large ones, because the heat lost in the beginning and end of the process, and that transmitted through the walls of the building, is the same in both instances.

Mr. Daniel Little of America, in 1785, recommended a new substance to be used in the cementation of steel instead of charcoal: it is the marine plant known by the name of rock-weed, or rockware, and is found in great plenty on rocky shores in America. It was to be prepared by first mowing it from the rocks by the scythe or sickle, and spreading it out on dry land till the rains have washed off the greater part of the sea-salt; it was then to be dried and pulverized, and may be used as any other cement for making of steel. He says that he discovered this property in an experiment where a small piece of iron was put into a crucible, and filled with the powdered plant as a cement: after it had been exposed to little more than a cherry heat for five or six hours, it was converted into steel.

All cemented steel in its raw state, after it is taken from the converting furnace, is called blistered steel; because the surfaces of the bars are covered with blisters, and on breaking a bar it is found to be full of cavities within, which seem to have been opened by some gas generated in the iron when in the process of cementation, and to have raised the surface into blisters, which are hollow within. In this state the steel is not fit for any purpose, because of these numerous cavities, and from the great disposition it has to break with the most irregular and rugged fracture imaginable. To render it sound and tenacious, it must be well hammered while at a moderate heat, which operation is termed *tilting the steel*, because it is done under the tilt-hammer, worked by machinery. There are many reasons why the hammering of steel cannot be sufficiently performed by hand: the principal are, that the expence of labour would be too great to answer, and that a man could not strike hard and quick enough, to complete the operation at one heat of the steel: if more than one heat is taken, the steel will not receive so much advantage from the hammering, because when it is heated, its pores are opened; and if suffered to cool without hammering, the grain of the steel will be found considerably coarser; therefore, every time it is heated, the good effects of the previous hammering are in a great measure lost. Tilt-hammers are worked by water-wheels or steam-engines, according to the local situation of the manufactory. (See a description in the article *TILT-Hammer*, Plate VIII. *Iron Manufacture*.) The same axis is made to actuate three or four tilt-hammers placed side by side, and the hammers are not all of equal lengths, each one being shorter than the next: by this arrangement, when they are all working together, the workman of one tilt does not incommode those employed at the other two. The anvils of the hammers are nearly on a level, or at most only a few inches above the surface of the ground; and the workman sits in a pit or fosse, dug for the purpose, in a direction perpendicular to the helve of the tilt, upon a seat which is suspended from the roof of the building by two

iron rods: by this means he can with the greatest ease advance to or from the hammer, by just touching the ground with his foot, and pushing himself backwards or forwards as he sits in the swing. The three seats are in parallel directions, but sufficiently distant from each other, in consequence of the different lengths of the hammers, to allow the workmen to perform their business. At a convenient distance from each tilt, is placed the forge for heating the steel. The two forges for the small hammers are placed together under the same dome, while the other forge is by itself near the great hammer. The bellows for the forges are worked by a small crank on the end of the gudgeon of the shaft; they are placed over-head in the roof of the building, and a copper pipe conveys the air to the tue iron. The forges are like those used by smiths, except that they have a small cover built of fire-brick over the hearth: the cover is square within, about eight inches wide, eight high, and eighteen inches or two feet long. It is open in front, to introduce the bars. The coals are placed on the hearth, as smiths usually do, and the brick cover acts, to reverberate the flame down upon the steel, and give a very regular heat. Each workman at the tilt is attended by two boys, who heat the steel at the forge, and convey it to the workman, that he may lose no time: another boy attends each tilt to take away the finished rods and cut them to length, and then to straighten them.

The operations of the tilt are conducted in the following manner: Suppose a piece of steel has been heated by one of the boys, and brought to the man at the hammer, he places it upon the anvil, at a part nearest to the centre of the hammer, where its surface is reduced to a round edge, about an inch wide: the face of the hammer is made round, to correspond with the anvil, and from its similarity to the edge of a smith's hammer, may be called the pen of the hammer and anvil. The machine is always in rapid motion, and between every stroke that the hammer makes, he moves the bar forwards on the anvil, that it may be struck by the edge of the hammer in a fresh place. If the bar is flat, as blistered steel usually is, it is first hammered in this manner upon its edge, to reduce it to a square, and at the same time draw it out in length. When it has been hammered thus all its length, the surface becomes indented on both sides by the edges of the hammer, the anvil being bounded by waving lines. This first operation is called *notching down*. The tilter then removes the bar beneath the flat face of the hammer, and the rod is flattened at every stroke, and all the indentation removed; when he gradually recedes from the hammer, drawing the rod along, and flattening it all the way. When the end of the rod comes under the hammer, he turns the other face of the rod upwards, and advancing to the hammer, pushes the rod forwards under it: in this manner he proceeds, flattening it on one side or the other, until he brings it to the proper size, which he tries by a gauge. The moment it is finished, the boy brings another piece of hot steel, which he places under the hammer, and then the other boy takes away the finished rod from the tilter, who takes the fresh piece: in doing this, they are careful that the hot piece of steel is placed under the hammer before the other is taken away, that the faces of the hammer and anvil may not strike together, when there would be danger of breaking them, as they are both made of cast-iron: the second piece is tilted in the same manner as before, and when finished, is changed for another.

The perfection of tilting steel, depends upon drawing out a rod perfectly straight to the same size in every part of its length. Many workmen, particularly at Sheffield, have acquired such skill and dexterity in the management of the rod while under the tilt, that their work is as straight and even

as though it had been drawn through a steel-plate, in the same manner as wire, and all its angles perfectly square: its surface is of a black polish, and as smooth as though it had been filed. All artificers use the square steel rods for making their tools; and the straightness and regularity of the rods are such, that a person who has not been an eye-witness of the operation, would scarcely believe it possible to produce such accurate work from the blows of a hammer. The points to be attended to by a tilter are, that in notching down the bar to draw it out to length and size, he causes the blows to fall exactly at equal distances from each other, unless (which seldom happens) the bar should have any part thicker than the rest; the strokes must then be a little nearer together in that place, to reduce it all to one size. Afterwards, to flatten the bar, he must be careful to place the bar truly flat upon the anvil, and hold it in the same place, whilst he draws the bar under the hammer, and that he moves himself with a perfectly equable motion, that every part of the bar may be alike subjected to the action of the hammer: the surface will then be true, and free from undulations. Another circumstance to be attended to is, when he turns the bar upon the anvil to hammer the adjacent sides, that he makes them truly square to the former sides. These things must all be done in so little time, that it requires long practice and experience to perform them well. Beginners are always apt, when they place their feet on the ground, to move themselves too quick just at that time, which causes the bar to be thicker at that place.

The different methods of conducting the operation of tilting, give the steel different qualities, which are distinguished into 1. Common steel; 2. Shear or Newcastle steel, also called German steel; and 3. Tilted cast steel.

Common steel is made by tilting bars of blistered steel, and drawing them out into rods of any size. The blistered bars are of various sizes, but in general about an inch and a half broad by half an inch thick. If these are to be drawn into rods half an inch square, they are broken into convenient lengths to handle, and one end of each piece is heated to a good welding heat by the boy who attends the forge, who puts three or four in the fire together, and, according to their size, he learns by experience at what time he must put every one into the fire, that it may acquire the proper degree of heat by the time that the tilter shall have just finished the other bars.

The tilter first begins by notching down the narrow edge of the bar, holding the other end of it in his hand, and notches down such a length of it as experience teaches him will be sufficient to form a rod of the length and size required. The notching on the edge of the bar rather increases its thickness, while it diminishes its breadth, and brings it nearly to the square figure of a rod: he then flattens it, and begins again to notch it down upon the broad side; afterwards he again flattens it; then proceeds to notch it upon the edge, and afterwards to flatten it once or twice on both sides, and the rod is finished.

When a skilful tilter has been some hours at work upon rods of one size, he judges by sight when the rod is of the proper size; but on first beginning, he tries it by a gauge, and flattens it repeatedly, if necessary, the boy bringing a piece of hot steel to place under the hammer while he is

gauging, and which is drawn out in its turn. When the tilting is completely finished, the steel rod is taken away by another boy, who, with a pair of shears, cuts off the rod from the blistered bar from which it was drawn out. He places the rod on a flat cast-iron table, and sets it truly straight by a hammer, then stamps the bar with a mark of the quality of the steel, and it is finished.

All these operations are performed in so short a time, that the rod still retains a red heat; but this will excite less surprise when it is considered that the hammer strikes four hundred blows *per minute*, and falls with great weight, so that it soon completes the work, and it is very probable that the great percussion it exerts upon the steel in some measure preserves the heat. It is well known that blacksmiths are in the constant habit of lighting a match to kindle their fire, by only hammering a small piece of iron quickly, and turning it about under the hammer, and in a short time it acquires sufficient heat to inflame the sulphur of the match. This heat most probably arises from the friction which the hammer causes amongst the particles of the iron, by rubbing them violently against one another; and the smiths observe, that the iron will not become red-hot if it is always struck upon the same side; but it must be turned round, that a new surface may be continually exposed to the action of the hammer.

Shear steel is so called, because the shears for dressing woollen cloth are made of it. It is also called Newcastle steel, because formerly made there; and German steel, because the natural steel in Germany is treated in the same way; it is likewise called *faggotted steel*. To make shear steel, the bars of blistered steel are broken into lengths of about eighteen inches; then four or more of these are laid together with one of double the length, and all four are tied together with pieces of small steel: this is called a faggot, and is placed in the forge, to be heated to a good welding heat; it is then taken to the tilt, and notched down on both sides, to weld all the bars together, and close up the internal flaws. The workman holds the faggot by the end of the long bar as a handle: the operation of welding takes but a few seconds, and a small rod is then drawn out from a piece of the end, in the same manner as drawing out common steel.

Cast steel is prepared by melting fragments of blistered steel, and casting them into an ingot. (See STEEL.) The ingot is then drawn out under the tilt into the required size, and the manner of doing this is the same as for common steel.

It is the custom of the manufacturers of cutlery and steel goods to purchase steel from the converting furnaces in the state of blistered bars, which they send to the tilt-mills to be drawn out to the size they require for their use: this is done at regular prices. In tilting steel, a trifling loss is sustained by the metal oxydating upon the surface, and throwing off black scales. The manufacturers are in the habit of allowing 4.6 to 8 lbs. *per* hundred weight for such loss: this latitude is given, because in drawing the bars out into rods of a small size, the waste must necessarily be greater; the metal being much longer exposed to oxydation, and the surface throwing off more scales.

Tin

TIN, *Stannum*, *Jupiter*, a whitish metal, softer, less elastic, and less sonorous, than any other metal, excepting lead. In the Chaldee language, תִּינ, *tin*, signifies *slime*, *mud*, or *dirt* ;

and when the Phœnicians came into Cornwall, and saw this metal in its ancient slimy state, they called it "the mud;" and hence, some have said, the name *tin*, in Cornu-British *stean*, is derived. Some of the ancients called it *plumbum album*, white lead, probably to distinguish it from common lead; not knowing that it was radically another metal.

This metal, denominated *κασσίτερος* by the Greeks, and *stannum* by the Latins, seems to have been known from the most remote ages. It is mentioned by Moses; see Numb. xxxi. chap. 22. It was transported to the East from Spain and Britain by the Phœnicians, with which nations they are said to have carried on a lucrative commerce. Homer mentions it; and by Aristotle, the epithet *Κελευκος*, or *Celtic*, is applied to it, indicating plainly the country from which it was procured. See *Tin-Trade of Britain*.

TIN-Stone, in *Mineralogy*, is the most common ore of tin, and is nearly a pure oxyd of that metal. The colour is brown, which passes from a blackish-brown to black, and from a red-brown to yellowish and greenish-white. It occurs crystallized and amorphous, and in grains and rolled pieces, varying from the magnitude of a grain of sand to that of an egg, or larger. The primitive form of the crystal is a flat octohedron: the angles are $112^{\circ} 10'$ and $67^{\circ} 50'$. The figure of the crystals is seldom perfect; sometimes a rectangular prism is interposed between the pyramids that form the octohedron. The edges and summits of the crystals are frequently bevelled or truncated, from which a great variety of secondary forms is derived. The crystals are also frequently united, forming compound crystals or macles: indeed, so numerous are the secondary crystals of tin, that more than one hundred and eighty forms of single crystals have been observed, besides the compound crystals, of which there is a considerable variety. The surface of the crystals is commonly smooth and splendent, but is sometimes streaked. The structure is laminar, but the laminæ are rarely visible. The fracture is uneven and imperfectly conchoidal, with a more or less shining and resinous lustre. When the laminar structure is displayed, the lustre is highly splendent. The crystals are semi-transparent or opaque, the darker colours being opaque, the lighter sometimes nearly transparent; and the intermediate shades are only translucent, or translucent at the edges. The streak is a greyish-white. Tin-stone is hard, scarcely yielding to the knife, and giving sparks with steel. It is brittle and heavy. The specific gravity varies from 6.759 to 6.970.

Before the blowpipe it decrepitates, and becomes paler; when finely pounded and mixed with borax, it is reducible on charcoal to the metallic state.

Tin-stone contains the following constituent parts, according to Klaproth.

	From Altonon.	Schlackenwald
Tin	77.50	75.
Oxygen	21.50	24.50
Iron	0.25	0.50
Silex	0.75	

Some analyses of tin-stone give from two to three *per cent.* of alumine. The tin-stone of Cornwall, dressed in the common manner, is reckoned rich if it yield 65 *per cent.* of tin. Tin-stone may be distinguished from *wolfram* by its superior hardness, as it gives sparks with steel; but wolfram yields easily to the knife. The powder of tin-stone is a greyish-white, that of wolfram a reddish-brown. It is distinguished from *blende* by its superior hardness, and its not emitting a sulphurous odour when pounded. By its greater specific gravity and lustre, it may be distinguished from *garnet*; and from *schorl*, by its colour, lustre, form, and higher

specific gravity. This ore occurs in veins and beds, and disseminated in granite rocks. The veins intersect rocks of granite, gneiss, mica-slate, and slate: tin-stone occurs also in alluvial soil in the districts that contain tin-veins. See *Stream-Tin*.

Wood-tin is a species of tin-stone, or oxyd of tin, found with stream-tin in rolled pieces, which are wedge-shaped or reniform, and sometimes globular. The structure is divergingly fibrous, with concentric laminæ; and from the supposed resemblance to the transverse section of fine-grained wood, it received its name. The colour is commonly hair-brown or wood-brown, passing into yellowish-grey. The lustre is glimmering or silky. It is opaque, hard, and brittle: the specific gravity is 6.450. It is infusible before the blowpipe, but is changed to a brownish-red colour. When strongly heated in a charcoal crucible, it yields about 75 *per cent.* of metallic tin. The constituent parts are, according to Vauquelin,

Oxyd of tin	91
Oxyd of iron	9

In Cornwall, this ore is almost always found with stream-tin, and never in veins: it is said, however, to have been recently met with in cellular quartz, but in very minute pieces. It is one of the most common ores of tin in Mexico, and occurs in veins that traverse a porphyritic trap, and also in alluvial depositions. In some wood-tin, there is a small, black, smooth globule, from which, as from a centre, the fibres diverge: this has received the name of *bird's-eye tin*. Wood-tin, in its structure and mode of formation, probably bears a near analogy to the kidney-shaped hematite iron-ore.

Bell-metal Ore, Tin Pyrites, or Sulphuret of Tin, is an extremely rare ore of this metal, being found only in Cornwall, at Huel rock, in a vein accompanied with sulphuret of zinc and iron. Its colour is steel-grey, passing into yellowish-white: it has a metallic lustre, and granular uneven fracture: it yields easily to the knife, and is brittle. The specific gravity is 4.350. It fuses into a black slag before the blowpipe, exhaling at the time a sulphurous odour. It communicates a yellow or green colour to borax. The constituent parts differ in different specimens; according to Klaproth, they are as under:

Tin	34	26.50
Copper	36	30.
Iron	3	12.
Sulphur	25	30.50
Earthy matter	2	
	100	99

Klaproth observes, that the darker varieties of this ore are considerably poorer in tin than the lighter, but the proportion of iron increases.

Analysis of the Ores of Tin.—The analyses in the *dry way* were made by Klaproth in charcoal crucibles in the following manner, in which the results were always found to be constant. The ore was broken, and well cleaned from the matrix. One hundred grains were introduced into the cavity of a charcoal crucible, closing its orifice with a stopper of charcoal. The charcoal crucible was then fitted close into one of baked clay, and placed upon the forge-hearth before the nozzle of the bellows. The contents in the charcoal crucible were reduced to the metallic state by exposing it to a strong blast for half an hour. The button of metallic tin produced was a little blackish on the sides,

and its surface coated with a greenish crust. From one hundred grains of Bohemian tin-stone, seventy-two grains and a half of tin were produced. Wood-tin and stream-tin were treated in a similar manner. Brown tin-stone, exposed to a porcelain fire in a clay crucible, formed a clear dense glass, greenish-grey in the middle, but of a bright yellow on the sides and top. The interior of the vessel was glazed, of a milk-white, and overlaid with many small groups of needle-shaped crystals of a light-brown colour. The inner surface of the lid was lined with similar crystals.

Analysis of Tin-Stone in the humid way.—To Klaproth we are indebted for the discovery of a simple and effectual mode of analysing tin-stone in the humid way. Boil 100 grains of this ore, finely pounded, with a solution of 600 grains of caustic potash. Evaporate to dryness, and then ignite the mass moderately for half an hour. Add boiling water, which dissolves the principal part of the mass, and the residue must again be ignited with six times its weight of caustic potash, and dissolved in water, as before. Add this to the last solution, and saturate the whole with muriatic acid, which will throw down an oxyd of tin. Let this be re-dissolved by an additional quantity of muriatic acid, and precipitated again by carbonate of soda; when lixiviated, and dried in a gentle heat, it acquires the form of bright-yellowish transparent lumps. This precipitate must be finely powdered, and once more dissolved in muriatic acid, assisted by a gentle heat. The insoluble part consists of filix. Dilute the solution, which is colourless, with from two to three parts of water, and introduce a stick of zinc, round which the tin will collect in a metallic state in the form of delicate dendritic laminæ. Scrape off the tin, wash, dry, and fuse it under a cover of tallow in a capsule placed on charcoal. A button of fine metallic tin will remain at the bottom, the weight of which, deducted from that of the ore, indicates the proportion of oxygen.

Analysis of Bell-metal Ore, or Tin Pyrites.—To two drachms of finely powdered ore, add one ounce of muriatic acid, and half an ounce of nitric acid: this will dissolve the greater portion of the metallic part without heat, but a gentle heat must be applied to dissolve the whole. The sulphur will float on the surface of the solution, and must be separated by filtration. To the solution add carbonate of potash, which produces a greenish precipitate; let this be re-dissolved in diluted muriatic acid, and introduce a cylinder of pure tin, the weight of which is to be previously ascertained. By this means the copper will be separated in a metallic state. The cylinder of tin must now be carefully weighed, and the quantity which it has lost must be noted, and a cylinder of zinc must be introduced into the foregoing solution: this will separate all the tin, which must be melted with tallow and weighed. Deduct the quantity of tin which was lost by the cylinder, and the remainder will be the quantity of tin from the ore, held in the solution.

The sulphur separated by the first filtration must be ignited, and the unconsumed residue, dissolved in nitro-muriatic acid, must be added to the solution, in order to obtain the whole of the contents. The undissolved part will be the siliceous matrix.

The copper may be briskly digested in nitric acid, which will leave behind a minute portion of oxyd of tin, and ascertain the precise quantity of pure copper contained in the ore.

The method of getting, preparing, &c. the tin in the Cornish mines, much the best and most considerable in the world, is given us in the Philosophical Transactions, Abr. vol. ii. p. 569, &c. and more distinctly and fully in Pryce's Mineralogy.

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The working of the tin-mines is very hard and difficult, not only by reason of the great depth which the veins descend to, even as low as sixty fathoms; but also because the rocks, through which passages are frequently cut, are extremely hard. Nor is the soft shaking earth found in the tin-mines much less inconvenient to the workmen, both by reason of the fetid, malignant vapours it exhales, and of the current of water often met with in them: these disadvantages often render it impracticable for the workmen to hold it above four hours together.

The existence of native tin has been always doubted, and till of late absolutely denied by all mineralogists, both ancient and modern: however, Mr. Borlase, in his Natural History of Cornwall, p. 185, suggested, that its existence was far from being improbable; but he afterwards discovered three specimens of this metal, native or pure, of which he presented an account to the Royal Society. Mr. Mendes da Costa made several experiments on one of these specimens, with a view of proving that it was really tin; from which he infers, that it is perfectly ductile and malleable; and being bent between the teeth, gives the same crackling noise as tin always does: in an open fire it melts easily, calcines on the surface, and smokes; but forced in a stronger fire with borax, it detonates with small phosphorescent sparks, which is a property of pure tin; and it is only corroded to a white calx in spirit of nitre, and oil of tartar *per deliquium* being added to the solution, none of it was precipitated: whence he concludes, that it was pure tin. Philos. Transf. vol. lvi. art. 7. 39. Native tin is also said to have been found in Saxony and Malacca.

The ores of tin may be generally classed into shoad or shode, stream, and bal or mine tin. The shoad is disjunct, and scattered to some distance from its parent lode, and is pebbly or smoothly angular, of various sizes, from half an ounce to some pounds weight. See SHOAD.

Stream-tin ore is the same as shoad, but smaller sized, &c. See STREAM-TIN and STREAMING.

Bal or mine tin-ore often rises very rich; and instances frequently occur, in which it has been discovered in the richest and purest state imaginable. This kind of rich ore consists of the blackest grains or crystals, and is usually found at a moderate depth, or within the day-side of forty fathoms.

When the tin-ore is raised, or dug and drawn out of the mine, and laid by the shaft, it is first *spalled*, as the process is termed, which consists in breaking it into smaller fragments, and separating it from the worthless parts. When the best parts are sorted, they are divided into heaps by a hand-barrow, containing a sack and a half, or eighteen gallons. Each of these shares, called *doles*, being turned over, equally levelled and mixed, is then divided with a shovel into two equal parts; and after being bruised by large sledges to the size of a hazel-nut, is equally levelled and divided into four parts: the bruising and divisions are repeated at pleasure, till the quantity designed for sampling is well mixed, and made as fine as common sand. To make a rough guess, or coarse essay, the sampler takes a handful of it, and washes it on a shovel, till the impure parts are carried off by the water, and the more solid and heavy particles, that are left behind, are bruised with a sledge on the shovel, till the whole assumes the appearance of mud. This is again washed, and by a peculiar motion the metallic particles are collected together on the fore-part of the shovel. By repeating these bruising, washings, and motions, it becomes clean black tin, fit for the melting-furnace. This is called a *van*, (probably from the French *avant*, *foremost*,) as it is thrown upon the point of the shovel by the dexterity

of the sample trier. After the tin is thus cleaned, it is dried; and if there be as much black tin as will cover a shilling, or equal to the weight of a shilling, it is called a *shilling van*, which is not rich; but if the van will cover or equal the weight of a crown-piece, it is good tin-stuff, and called a *crown van*. The shilling van, the tanners say, will produce one hundred avoirdupois weight of block or white tin; and the crown van will yield five hundred weight of block tin, for every hundred sacks in measure of the respective doles from which the sample or van was taken, and so in proportion, to the richest tin-stuff, called *scove*, which is reckoned at the rate of ten thousand of white tin-metal for every hundred sacks. But a better judgment may be formed from the measure of a wine half-pint, than from a handful, which is indeed accounted a half pint. When the tin, thus measured, is reduced clean, and to a proper size, by using a large shovel, and taking off the sized tin on another shovel, the van is dried in a shovel upon the fire, and then weighed by pennyweights and grains; and for every pennyweight and a half the van weighs, the produce will be one hundred weight of black tin for every hundred sacks of tin-stuff; and for three pennyweights, two hundred weight, &c. in the same proportion; and if it be tin worth ten for twenty, or one for two, then the tin-stuff is valued at five hundred weight of block or white tin for every hundred sacks: if it be worth twelve for twenty, the stuff is valued at six hundred weight of white tin a hundred; or if it be worth only eight for twenty, it is only valued at four hundred weight of white tin a hundred, &c. This black tin is rather of a liver colour, though called black in contradistinction from white tin, or the metal produced from this black ore: it is very heavy, and may in general be computed to hold one-half clean metal, and some of it will produce thirteen, or even fourteen parts in twenty; whence the mode of expressing so much white tin for twenty of black tin, *i. e.* eight for twenty, ten for twenty, twelve for twenty, &c. Thus, if the van of one hundred sacks of tin-stuff weighs six pennyweights, being four hundred weight of black tin at twelve for twenty, the white tin or metal must be two hundred weight one quarter sixteen pounds.

In this method of sampling, the tanners form a near conjecture of the quantity of white tin which their doles of tin-stuff will produce at the smelting-house, when it is dressed, and brought into black tin. But if the black tin is combined with any bad mixture, as of mock-lead, copper, or mundic, after the van is bruised fine and washed, they lay the shovel over the fire, and burn the black tin, stirring it continually, till it has done smoking: they then wash it again on the shovel, and thus the heterogeneous matter, becoming light by being burnt, is carried off by the water: for when black tin is calcined or burnt, it still retains its specific gravity; but copper, lead, and other crude minerals, become much lighter by torrefaction, and are easily separated from the tin by water. In the dressing and management of tin by stamping, &c. there are obtained two sorts of black tin, *viz.* the crop and rough, or the crop and leavings of tin. The first is the prime tin: immediately separable from the baser parts by its superior weight and richness. The latter is that which is carried off, and mixed with the lighter earthy parts, by being under size, and, therefore, more easily carried off by the water.

The tin-stuff, after this previous preparation and adjustment, is carried to the stamping-mill, in order to be dressed or pounded.

This operation of pounding in the stamping-mill is essential to the complete separation of the ore from the matrix,

through which it is disseminated. If full of slime, it is thrown into a pit, called a *buddle*, to wash away the earthy matter, and render the stamping more free, without choaking the grates. The ore is shovelled into a kind of sloping canal of timber, called the *pasi*, whence it slides by its own weight, and the assistance of a small stream of water, into the box where the lifters work: the lifters are raised by a water-wheel, and are armed at the bottom with large masses of iron, weighing nearly two hundred weight each: these pound or stamp the ore sufficiently to enable it to pass through the holes of an iron grate fixed at one end of the box. To assist its pulverization, a rill of water keeps it constantly wet, and it is carried by a small gutter into the fire-pit, where it makes its first deposition; the lighter particles running forward with the water into the middle pit, then into a third, where what is called the *slime* settles. (See *Dressing of ORES*, and *BUDDE*.) From these pits the ore is carried to the *keeve*, which is a large vat containing water; in which it is farther purified by an operation termed *packing*, and which consists in beating the upper part of the contents with mallets for some minutes, by which the lighter particles are kept suspended, whilst the tin-ore, from its great specific gravity, subsides. The waste is skimmed and laid by, to be again buddled, under the name of the *skimpings*. The tin is sifted through a copper-bottom sieve into another keeve of water, by which the gravelly waste still remaining is separated from the clean tin; and the tin that runs through the sieve, if it requires no farther buddling, may be cleaned by repeatedly tossing and packing it as before. If it be necessary to buddle it again after it is sifted, let it be buddled and distributed in three parts, *viz.* the crop or purest, the crease or next in purity, and the hind-crease or tail, which is the most impure. The crop is to be cleaned by tossing, &c. and the crease must be buddled again, and out of this must be reserved as much as may be cleaned by tossing and packing. The remainder must be cleaned by an operation called *dilleughing*, from *dilleugh*, to let go, or send away. A dilleugh is a large fine hair-sieve, which the dresser holds in a keeve one-third full of water, into which the tin is thrown by a shovelful at a time, and which is shook so as to put the tin into motion: one side of this dilleugh is dipped in water, and raised again in such a manner, that the waste may run over, which is laid aside to mix with the skimpings, to make the samples of low value, called the *rough* (or *row*) tin. This usually undergoes another operation, in which, by a rill of water passing over the buddle in which it is placed, it is farther cleaned, and then dilleughed, so as to be fit to mix with the crop tin.

Upon the same mechanical principle of separation, the tinner is capable of estimating the value of a sample of ore. For this purpose, the pounded tin-ore, or tin-stuff, as it is called, is placed on a shovel and washed under a stream, till the impure earthy parts are carried off by the water from its sides, when, by a particular and dexterous motion, not easily described, all the metallic particles are collected together on the fore-part of the shovel: this operation is called *vanning*, which we have already described.

When the tin-ore is contaminated with the different pyritous ores of copper, arsenic, and iron, it is first roasted in a burning-house, and then washed in water, by which means the tin, which is heavy, is easily separated.

By this process, as at present conducted in Cornwall, a considerable quantity of copper is lost; for being converted into sulphate of copper, which is soluble in water, it is lost by washing: whereas, if the roasted ore were suffered to remain in a close pit for a few days, and the water drawn

off into another pit, the copper might be separated by iron in a metallic state.

The leavings of tin, consisting of the slime and tails, *i. e.* of tin-mud and tin-gravel, are dressed by a particular kind of apparatus, for the construction and use of which, we must refer to Pryce's *Min. Corn.* p. 226, &c.

Each stamping-mill, which has constant work and water, will employ one man and five boys; and one hundred sacks are carried, stamped, and dressed, in the space of a few days, at the average rate of about four-pence *per* sack, or one guinea and a half *per* hundred.

When the tin-ore is dressed, it is divided into as many shares as there are lords and proprietors.

The next operation pertaining to tin-ore, or black tin, is that of *smelting* it. The Phœnicians, who traded to Cornwall for tin in the earlier ages, probably conducted this process by digging a hole in the ground, and strewing the ore on a charcoal fire, which perhaps was excited by a bellows. But having no idea of confining the fire, and directing its force on the substance to be smelted, they made no use of furnaces, either simple or reverberatory. Charcoal was long used in the operation of smelting, till at length necessity suggested the introduction of pit-coal; and in the second year of queen Anne, a patent was granted for smelting black tin with fossil coal in iron furnaces. The invention of reverberatory-furnaces built with brick, stone, sand, lime, and clay, soon followed this discovery; the form of which, being simple, has admitted of little improvement to the present time. The charge for one of the tin smelting-furnaces is from five to six hundred weight of black tin, well mixed with a tenth or twelfth or eighth its weight of culm, which is a species of coal from South Wales, that is very free from sulphur. The furnace is charged through a hole in its side with a shovel, and the tin levelled over the bottom with an iron rake or paddle. The apertures are then closed, and the fire raised to a very great strength, in which state it is left for four or five hours, when the door is taken off, and the whole charge well stirred together. The state of the metal is examined, and more culm thrown in if necessary; the furnace is again closed, and the fire kept up till the end of about six hours from its receiving the charge; when it is again examined, and if proper, it is then *tapped*, and the metal let out into a fixed basin made of clay, and large enough to hold somewhat more than the metal of the charge. The scoria in the bottom of the furnace is *raked* out at the mouth into a small pit made for this purpose, where it generally forms itself into a cake. When cold, it is carried to the stamping-mill, in order to separate the globules of melted tin disseminated through the scoria or slag. This, being broke by hammers to the size of goose-eggs, is put into the first stamping-mill, and passed through small iron bars; by which means the *pillion* (for so all tin recovered out of the slags is called) of the larger size is taken out and prevented from waste by too much stamping. The refuse of this first stamping is put into other stamping-mills of a second, third, or even fourth size. Of the pillion, separated from the scoria, all the rough or grainy parts are considered as metals, and refined accordingly, by being smelted without any flux, and the produce of this smelting refined, with the tin first tapped.

The tin in the basin, or float (as it is called), as soon as it comes down to a moderate heat, is laded out into the moulds, in slabs or pigs of about three-fourths of a hundred weight.

The method of smelting in Saxony and Bohemia, does not differ greatly from that practised in Cornwall. When the ore has been roasted it is washed upon tables, to separate

the oxyd of iron and the oxyd of copper, which are lighter than tin-ore. At Alt-Saint-John, the oxyd of tin is mixed with the black oxyd of iron: this is separated by a powerful magnet, which is drawn over the table. That the powdered oxyd of tin may not be blown away by the blast of the furnace, it is previously moistened with water; but as the flame always carries away a part of the ore, a chamber is constructed about the middle of the chimney, made of wood lined with clay, where the powdered ore that has been driven up by the flame is deposited.

The next process is that of *refining*. The furnace having, by the side of the small float now described, a larger one capable of holding twenty, or more blocks, is for this purpose suffered to cool to a certain degree, and then charged full with the slabs just mentioned, the tap-hole being kept open, so that as the tin melts in this moderate fire, it makes its exit through it into the float; where, while running out, it is frequently stirred and tossed by a ladleful at a time held arm-high, letting it fall in a stream into the mass of metal, when the scum which arises is taken off. While the metal already put into the furnace is melting, more is added, so as to be just enough to fill the float with good tin: and this, after being tossed and skimmed as before, and suffered to cool to a proper temper, is carried in iron ladles to moulds holding generally somewhat above three hundred weight (then denominated *block-tin*), where they are marked as the smelters chuse with their house mark, which may be a pelican, plume of feathers, stag, or horse, by laying brass or iron stamps, in the face of the blocks while the tin is in a fluid state, and yet cool enough to sustain the stamping iron. The blocks are then ready to be weighed, numbered, and sent to the nearest coinage town to be coined. The privileged towns for coinage of tin, were anciently Liskeard, Loftwithiel, Truro, and Helston: but soon after the Restoration, Penzance was added to the number; in which last place there is every quarter more tin coined than in the towns of Liskeard, Loftwithiel, and Helston, for a whole year. When the tin is brought to be coined, the assayer's deputy assays it by cutting off with a chisel and hammer a piece of one of the lower corners of the block, about a pound weight, partly by cutting and partly by breaking, in order to prove the roughness and firmness of the metal. If it is a pure good tin, the face of the block is stamped with the duchy seal, which stamp is a permit for the owner to sell, and at the same time an assurance that the tin so marked has been examined and found merchantable. The stamping of this impression by a hammer is *coining* the tin, and the man who does it is called the *hammer-man*. The duchy seal is argent, a lion rampant gules, crowned or, within a border garnished with bezants.

The drossy part remaining in the furnace is by an increasing fire wholly melted, which is then tapped into the small float, where the tin subsiding, and the dross rising to the top, the latter is taken off, and the tin laded into small slabs, as at first, to be again refined. The tin that remains in and about the scoria and dross of the last tappings, &c. is recovered by repeated smeltings, till at last, being almost entirely drained of that metal, they become what the workmen generally call *hard heads*, and esteemed of no farther value.

M. Grosse, in the Memoirs of the Academy of Sciences of Paris, has delivered a method he had invented of separating tin from lead or silver. Having tried an experiment on the scoræ of metal, which contained with the tin a large quantity of silver, it seemed to him that one great step toward the separation of the silver, was the hastening of the calcination of the tin, and with this view he tried a mixture

of charcoal, saltpetre, and earth, which he put together into the coppel with the scoriz. It is easy to see that a detonation would happen from this, and this must greatly add to the force of the fire, in acting upon the scoriz, while the ferruginous matter well known to be contained in the charcoal mixed itself with the tin, and must greatly accelerate its calcination, divide its parts, and give the fire a new action over it. The consequence of this perfectly answered expectation, and recovered a large quantity of silver from the scoriz, in which the tin had before held it firmly imbedded; repeated experiments proved the truth of this observation, and it was found to be easy by this means at any time to separate silver from tin, or to purify silver without loss, by means of lead in which tin has accidentally been imbedded.

The scoriz in which tin is mixed with silver, are composed of tin half calcined, and run into an opaque vitrified substance, which forms a sort of net-work, in which the silver is confined in extremely small particles. If this is thrown into aqua fortis, the whole is dissolved: but then it requires a very strong fire to make the tin lose its metallic form; finally, if the whole is finely powdered, and then put into this menstruum, the silver only is taken up or dissolved, the tin remaining untouched at the bottom of the vessel.

The same gentleman found also a method of separating tin from silver, by means of corrosive sublimate of mercury. To conceive the manner in which this separation is effected, a piece of fine tin need only be cast into a solution of sublimate; in which case the acid of the sea-salt is seen to leave the mercury in order to fix upon the tin.

And, according to the same principle, if sublimate corrosive be added to a mixture of tin and silver, the same effect is produced, the acid affixes itself to the tin, and makes with it a *butyrum joviale* or butter of tin, the mercury becomes dissipated in the mean time by the action of the fire, and the silver remains pure and alone; but in this experiment, if too much corrosive sublimate be added, there is danger of losing some of the silver; since the abundant acid will prey upon and carry off a part of that metal, making a sort of *luna cornea* which dissipates itself in the air, or if the operation be performed in a close vessel, a *butyrum lunare*.

Gold may also be purified from tin in this manner, and in this there is no risk of loss, since the acid which takes up the tin has not the least power over that metal: in all these processes, however, the operator must avoid the fumes issuing from the crucible, for they are very dangerous.

These methods of separating of tin from silver are very certain and infallible, but they are too expensive to be employed in common, and in larger works.

The separating of tin from lead to be employed in the refining of silver is a matter of great importance; and this may be done in the following manner: melt the lead, and when in fusion throw into it a quantity of filings of iron, then increase the fire to a considerable degree, and the surface of the metal will be covered with a sort of scum, which is no other than the iron and tin. At this time there should be a little alkali salt thrown in, and by this means the scoriz readily separate themselves, and the pure lead remains in form of a regulus at the bottom. The same method may be used to separate tin from silver in the larger way, but it will be necessary for this purpose to add some lead, since otherwise the fusion will be very slow and difficult, and the tin will calcine without separating from the silver. This is a very easy and very cheap method, and will obviate most of the mischiefs which happen to the refiners, of which they would have much less frequent reason to complain, if they

nicely examined the lead they were to employ. But if gold or silver be mixed with tin, the shortest method in small quantities is to calcine the whole very briskly, and in order to complete the vitrification and separation of the tin, to cast in a little glass of lead, which will immediately join itself with it and carry it off from the mass.

It may seem singular that iron being one of the hardest of the metals to melt, and tin being of all the easiest, they should so readily and easily unite in these experiments; but this seems to be the result of one of those natural and unexpected alliances which accident frequently discovers to us in bodies. There is one conjecture, however, that may be worthy a place in this research, which is, that all tin-ore contains a quantity of arsenic; and it is well known that iron very readily mixes with arsenic, and is employed to separate the arsenic from other ores, and a regulus may be formed of arsenic and iron. It is easy to suppose that tin is, in its metalline form, not wholly divested of the arsenic it contained when in the ore; and if this be allowed, it is no wonder that the two metals are easily brought together by the mediation of that principle. *Memoirs Acad. Scienc. Par. 1737.*

Mr. Cramer gives the practical rules of separating silver from tin, thus: Divide one centner of tin into two equal parts; put each of these into a separate test, and add to each sixteen centners of granulated lead, and one of copper; put the whole under the muffle, and make a very strong fire; the tin will be calcined immediately, and will swim upon the lead. Then diminish the fire a little, till the ashes of the tin that swim upon the surface do no longer sparkle: when you see this, add with a ladle two centners of glass of lead to each test, in such a manner that it may be spread wide over the whole surface of the rejected calx; the calx will then change its form of powder into that of glass; then increase the fire to its highest degree, stir up the whole with an iron rod made warm; and when the scorification is perfected, pour out the glass into a mould; the scoriz being separated, put both the reguluses into two coppels well heated; and into a third put sixteen centners of lead, and one of the same copper used in the process: examine all these beads after the cupping is over; if the two first weigh exactly alike, it is a proof the process has been well performed; and subtracting the weight of the bead, separated from the third pan, from the joint weight of the other two, the remainder is the weight of the pure silver contained in the quantity of tin which was examined. *Cramer's Art of Assaying, p. 228.*

Tin is found in Europe, Asia, and America, but has not hitherto been discovered in the continent of Africa. This metal is much less generally disseminated than gold, silver, iron, copper, or lead; but where it occurs, it is most frequently in large quantities. In Asia it is found on the coast of Sumatra, and in Siam and Pegu. It is principally imported into our Indian possessions from Queda, Junkfeilon, Tavai in Lower Siam, and the island of Banca. The tin-mines of Banca are said to be of great extent; and Mr. Ellmore informs us, that no less than from forty to sixty thousand peculs of tin are furnished by these mines annually. Tin is said also to be found at a place five days' journey from Nankin in China. The Indian tin was known to the ancients. Diodorus Siculus mentions it among the productions of India. Tin-stone is found in Mexico in the state of stream-tin, and is procured from alluvial depositions by washing. It is also said to occur in Chili.

Tin-ore occurs in Saxony and Bohemia in beds, and disseminated in granite rocks; it is found also in veins in rocks of granite, gneiss, and mica-slate. Alluvial depositions of tin are also met with in these districts. The mines sometimes consist of a mass of ore formed by the junction of a multitude

of small veins which pass through the rocks in different directions. These veins also contain topazes. Brongniart *Traité Elementaire*.

Tin is found near Monterey, in the province of Galicia in Spain, in veins which traverse granite and mica-slate. This ore has recently been discovered in small quantities in grains and crystals, in a rock of granite at Puy les Vignes, in the vicinity of St. Leonhard, in the department of Haute-Vienne in France. It occurs in veins with wolfram, arsenical pyrites, and martial arseniate of copper.

The most considerable repository of tin-ore in Europe is that of Cornwall. The greatest part of the tin consumed in Europe is procured from thence; and Camden even supposes this abundance of tin in Cornwall and Devonshire, to have given the original denomination *Britain* to the whole kingdom. In the Syriac language, *varatanac*, or *baratanac*, signifies *land of tin*; from which Bochart derives the name *Britain*. It occurs in Cornwall, both in veins and alluvial depositions, in various parts of the county. Alluvial depositions of this ore are also met with on Dart-moor, in Devonshire. The veins which contain tin intersect both granite and slate rocks; the latter are provincially called *killas*. These veins vary in width, and sometimes contain large masses of the ore. One block was raised from the mine called Polberrow, in St. Agnes, which weighed more than twelve hundred pounds, and produced more than half that weight of pure metal. Tin-stone generally occupies the upper part of veins, and is succeeded by copper-ore; but there are instances of tin occurring at the depth of two hundred fathoms. Different modifications of the forms of the crystals are peculiar to certain veins. Crystals of tin-stone are also disseminated in some of the granite rocks in the vicinity of veins: the crystals appear to occupy the place of mica. Where the tin-stone is disseminated in slate, it is generally in small strings or minute veins. See *MINE* and *VEINS*.

The workmen distinguish several kinds of tin; as *moor-tin*, which is the best sort, a fool of which weighs eighty pounds; and *mine-tin*, which is the next, the fool of it weighing about fifty-two or fifty pounds. The tin got from the soft, gravelly earth, they call *pryan-tin*, to distinguish it from that obtained from the stones, which is better by almost half. See *STREAM-Tin Ore*.

Grain-tin denotes the ore of tin that is sometimes dug very rich in the form of grains or pebbles, or else in larger pieces, composed of many such distinct grains, united in one mass, always of a black or dark rosin colour, pointed like diamonds. Grain-tin is also used to signify the purest and finest block or white tin, smelted with charcoal in the blast or blowing-house furnace, which never had any brood or foreign mixture in the mine: whereas the mine-tin is usually corrupted with some portion of mundic, or other mineral, and is always smelted with a bituminous fire, which communicates a harsh sulphurous quality to the metal. Grain-tin is peculiarly produced from stream-work, and is worth several shillings per hundred more than mine-tin. See *STREAMING*.

See on this article Macquer's Chem. Dict. art. *Tin*; and Pryce's Mineralogia Cornubiensis, fol. 1778.

There is a curiosity in the Cornish mines, which is this: that in digging at the depth of forty or fifty fathoms, they frequently meet with large timber, still entire.

Childrey, in his Natural History, goes back as far as the deluge to place them there; but, without having recourse to so great antiquity, they who believe that the mines, when exhausted of their ore, or mineral matter, renew and fill again in course of time, will soon solve the difficulty, by supposing

that, in the first working of these mines, these timbers had been let down to serve as props and pillars.

But there are other people who will think this renewal of the mines itself a difficulty as great as the former. However, what the former author adds, viz. that in some places in the mines they likewise find pick-axes, &c. with wooden shafts, as also brass nails, and that even a medal of Domitian has been found in one, seems to countenance the opinion.

For the use of tin in the composition of pewter, see *PEWTER*.

Tin-Trade of Britain. That tin was procured from Britain in a very early age, appears probable from the concurrent testimony of the most ancient historians. The Phœnicians are said by Strabo to have passed the pillars of Hercules, now the straits of Gibraltar, about twelve hundred years before Christ. At what precise period they discovered the Cassiterides, or Tin islands, is unknown, nor is their exact situation determined; but it is generally believed that the Scilly islands, and the western part of Britain, were the places from whence these early navigators procured the tin which they exported to other countries. The Phœnicians were extremely anxious to conceal from the rest of the world the true situation of the Cassiterides. Herodotus, who wrote about four hundred and fifty years before Christ, could not learn where these islands were situated; but he supposed that tin, like amber, was brought from the remotest parts of Europe. Strabo relates, that the captain of a Phœnician vessel returning from Britain seeing himself pursued by a Roman galley, chose rather to run his vessel among the rocks, than the Romans might experience the like fate, than be the means of discovering so valuable a commerce to the enemies of his country. The captain having escaped from the wreck, claimed from his country compensation for the loss of his vessel and the cargo; and it is said he was paid from the public treasury the amount of his claims. By these precautions, the Phœnicians are said to have enjoyed a profitable trade to these islands for about three hundred years. The secret was at length discovered, and the Greeks, Gauls, and Romans, came in successively for a share of this trade. The Phœcean Greeks established a colony at Marseilles five hundred and forty years before Christ; and after the destruction of Carthage, carried on this commerce: they endeavoured to conceal from the Romans their knowledge of the British isles; for on being questioned by Scipio respecting the situation and extent of those isles from whence the tin was brought, they declared that they were entirely unknown to them. The Phœnicians, in their voyage to Britain, are said to have sailed from Cadiz to the harbour of the Artabaci, near Cape Finisterre, from whence, after four days' sail, they arrived in Britain. Strabo relates, that Publius Lucius Crassus having made fruitless attempts to discover whence the tin was brought, at length succeeded, and arrived in Britain. It is uncertain when this Crassus lived, and even who he was, there being two of this name; the father, who was proconsul of Spain, and the son, who had a command under Cæsar in Gaul.

Diodorus Siculus, who wrote during the time of Augustus, appears, from the quotation which we shall subsequently give, to have been well acquainted with the tin-trade of Britain at that period. There cannot be a doubt, that from the conquest of Britain by the Romans, to the decline of their empire in the West, they enjoyed the undisturbed possession of the British tin-trade.

What the ancient method was of preparing tin for the furnace we cannot learn, says Dr. Borlase. Polybius the historian is said to have described it; and that work is com-

mended by Strabo, but now lost. The short description of the tin-trade given by Diodorus Siculus deserves particular attention. "These men (the tinnerns) manufacture the tin by working the grounds which produce it with much skill. For though the land is rocky, it has soft veins running through it, in which the tinnerns find the treasure, which they extract, melt, and purify. Then shaping it by moulds into a cubical figure, they carry it off to a certain island lying near the British shore, which they call Ictis; for at the recess of the sea between the island and the main land, the passage being dry, the tinnerns embrace the opportunity, and carry the tin over in carts to the Ictis or Port; for it must be observed, that the islands which lie between the continent and Britain have this peculiarity, that when the tide is full they are real islands, but when the sea retires they are so many peninsulas. From this island the merchants bring the tin of the natives, and export it into Gaul; and finally through Gaul, by a journey of about thirty days, to the mouth of the Rhone:" lib. 4. Pofidonius, as quoted by Strabo, says the port to which tin was brought in the south of France was Marseilles.

To what uses the nations of antiquity applied all the tin which they obtained with so much labour from Britain, is not precisely known. The Phœnicians were celebrated for their skill in the art of dyeing; and the Tyrian purple, which was either a bright crimson or a scarlet, was held in the highest estimation; hence it has been conjectured, with much probability, that the Phœnicians were acquainted with the use of the solution of tin in the preparation of that colour. In the modern art of dyeing scarlet or crimson, the solution of tin in the nitro-muriatic acid is essentially necessary to communicate those colours to woollen cloths or stuffs, a practice which is probably derived from the ancient manufactures of the East.

The mirrors of the civilized nations of antiquity were made of a composition of copper and tin. The most ancient account that we have of these mirrors is that in Exodus, chap. xxxviii. 8. "And he made the laver of brass (a mixture of copper and tin), and the foot of brass of the mirrors of the women." The Jewish women probably received these mirrors from the Egyptians when they left the country; for it was the custom of the Egyptians to carry a mirror in their left hand, when they went to their temples. Cyril de Ado.

Pliny says that the best specula were anciently made at Brundisium of copper and tin. The metallic mixture of tin and copper, for rendering the latter metal white, is mentioned by Aristotle. (De Mirab.) This composition is still in use for the specula of reflecting telescopes. (See SPECULUM.) The ancients also made use of an alloy of tin with copper and lead for pot-metal. In the time of Pliny, pot-metal, *ollaria temperata*, was made of two pounds of lead, and an equal quantity of tin, mixed with one hundred pounds of copper. From the same writer we learn, that the bronze of which the Romans made their statues, and the plates on which they engraved their inscriptions, was composed of one hundred pounds of copper, mixed with twelve pounds and a half of an alloy made of equal parts of lead and tin. He informs us also that tin, *plumbum album*, was employed in coating or tinning copper vessels, to render them more wholesome; and it appears that the Romans not only used pure tin, but the same mixture of tin and lead which some of our workmen use at this time in tinning of vessels. A mixture of equal parts of tin and lead they called *argentarium*; a mixture of two parts of lead and one of tin they called *tertium*; and with two parts of tin and

one of lead, they tinned whatever vessels they thought fit. (Watson's Chemical Essays, vol. iv.) In the manufacture of arms, the ancients used an alloy of tin with copper, their brass being a composition of these metals; but by what method they were enabled to communicate to it the necessary degree of hardness is unknown.

What was the relative value of tin, compared with that of gold and silver, as estimated by the Phœnicians, the Greeks, or the Romans, is uncertain.

The process of extracting tin from its ores was probably very imperfect, and remained so in this country to the time of Elizabeth, when Carew informs us that sir Francis Godolphin introduced great improvements in the tin-works.

The reverberatory-furnace appears, from Dr. Borlase, to have been introduced into Cornwall about the beginning of the last century; and about the same time the introduction of pit-coal became general, the wood of the country having been nearly exhausted. Sir Bevil Granville had previously made many experiments for melting tin with pit-coal, but without success, when the ore was smelted at the blowing-houses by large bellows worked by a water-wheel.

Whether the Phœnicians or the Greeks interested themselves in the management of the tin-mines, or whether they were simply merchants purchasing and exporting the tin, is uncertain. It appears, however, by the passage quoted from Diodorus Siculus, that the veins of tin-ore were worked as mines; though it has been, and is still generally believed, that stream-tin was the only ore worked by the ancients. From the testimony of Strabo, Pliny, and others, the Romans not only traded to Britain for tin, but improved the art of mining in Cornwall. The Romans being the conquerors, and the British under them having probably little or no property, they were the working miners, but under what regulations is uncertain. The Saxons did not obtain possession of Cornwall till the reign of Athelstan, and neither they nor the Danes appear to have directed their attention to the mines. After the Norman conquest, the working of mines is said to have yielded great profit. In the time of king John, however, the right of working tin being as yet, says Borlase, wholly in the king, as earl of Cornwall, the property of the miners was precarious and unsettled, and all the tin that was raised was engrossed and managed by the Jews. The tin-farm of Cornwall at this time amounted to no more than one hundred marks, according to which valuation, the bishop of Exeter received then, and still receives from the duke of Cornwall, the annual sum of 6*l.* 13*s.* 4*d.*, so low were the tin profits then in Cornwall; whereas in Devonshire, the tin was then farmed at 100*l.* yearly. King John, sensible of the languishing state of the mines, granted the county of Cornwall some privileges, and is said to have also granted a charter to the tinnerns.

In the time of Henry III. the tin-mines of Spain, which had been worked by the Moors, were stopped, and Cornwall had all the trade of Europe for tin. In the eighteenth year of Edward I., the Jews being banished the kingdom, the mines were again neglected for want of proper encouragement to labour, and security to enjoy and dispose of the products. In consequence of a petition from some Cornish gentlemen to Edmund, earl of Cornwall, a charter was obtained with more explicit grants of privileges of keeping courts of judicature, and managing and deciding stannary causes. About this time, says Borlase, it appears that the rights of bounding or dividing tin grounds into separate portions, for encouraging the search for tin, were more regularly adjusted, and various laws introduced for the protection of the miner.

In the thirty-third year of Edward I. the above charter seems to have been confirmed, and the tinnors of Cornwall were made a distinct body from those of Devonshire, before which time the tinnors of both counties were accustomed to meet on Hingston-Hill every seventh or eighth year, to concert the common interest of both parties. Two coinages of tin yearly were also granted by this charter, and the tinnors had the liberty of selling their own tin, unless the king insisted on buying it himself. Other laws and regulations for the encouragement and protection of the miners, were passed in the reigns of Edward III., Henry VII., and Elizabeth. The mines having been much neglected during the reign of Mary, Elizabeth invited German miners into the country, and great encouragement was given to mining operations in Cornwall, and various parts of England. The quantity of tin procured annually in the succeeding reigns of James I. and Charles, amounted to sixteen hundred tons. During, and for some time after the civil wars, the tin-trade declined, but revived again in the reign of George I., and has since been increasing. For an account of the annual products of the tin-mines of Cornwall and Devonshire, see the article *MINE*.

All the transactions connected with the tin-mines are under the controul of the stannary laws: courts are held every six months, and they decide by juries of six persons, with a progressive appeal to the lord warden and lords of the duke of Cornwall's council. By whatever method or accident a vein is discovered, permission of the proprietor must be obtained before any operations can be commenced, except in the case of such tin-mines as are anciently embounded according to the provision of the stannary laws. (See *STANNARY COURTS*.) The owner of the soil is technically called the *lord*, whose share (which is called his *dufb*) is generally one-sixth or one-eighth of the ore. The duke of Cornwall receives a duty of four shillings *per* hundred weight of tin, which is taken when the tin is assayed and licensed: this process is called the *coinage*, from the French word *coin*, a corner. A corner is chipped off each block at the office, and if it be found sufficiently pure, the blocks are stamped with the arms of the duke. The annual revenue of the tin is about 10,000*l.*; the average annual amount being about 3200 tons, and the value about 120*l.* *per* ton. The mode of assay is obviously rude and imperfect; and we have heard that foreigners have recently complained that the British tin was not so pure as that obtained from the East. But whatever be the purity of British tin, there can be no doubt that it is greatly adulterated on the continent. It is said that every tin-founder in Holland has English stamps, and be the quality of the tin what it may, the inscription makes it pass for English. The metal with which British tin is adulterated on the continent is lead, which being five times cheaper, and when mixed in small quantities not easily detected, the temptation for such fraud is great. It is not true, as asserted by some foreign writers of respectability, that British tin is purposely alloyed with certain portions of copper and lead before it is exported from Cornwall. The ores of tin, in the tin-mines of Cornwall, are so intimately associated with portions of copper-ore, lead-ore, arsenical pyrites, and other metals, of which a small mixture will remain in the block-tin, and can only be separated by subsequent refining, that any considerable portion of alloy may be detected by the increase of specific gravity. Grain-tin, which is the purest tin of commerce, is smelted from the finest ore by a charcoal fire: the common block-tin is smelted with pit-coal or culm, as

before stated. Grain-tin is used for various purposes in the arts, where tin of the purest quality is required.

Long as the tin-mines of Cornwall have been worked, they still continue to supply in abundance this useful metal; but from the greater extent of the present works, and from the circumstance of tin always occupying the upper part of the vein, we may infer that the tin-mines of that county will be exhausted at no very distant period. At present, the principal part of the tin is obtained from the western extremity of the county; but when the tin-mines in that district are worked out, we may consider the tin-trade of Cornwall as nearly extinct. The granitic range of Dartmoor, in Devonshire, has been less explored than Cornwall; but there is reason to believe that the metallic repositories of tin and copper which it contains will furnish an ample field for the industry of future adventurers, and a failure in the supply from Cornwall would greatly enhance the price of this metal, and give increased spirit to mining speculations.

TIN, in Chemistry and the Arts. The colour of tin is white, like that of silver: it has a sensible taste, and when rubbed, emits a peculiar smell: its hardness is greater than that of lead, and less than that of zinc: its specific gravity is stated by Briffon to be 7.291, and it is said to become a little greater by hammering: it is very malleable, and may be beaten into very thin leaves. *Tin-foil*, as it is termed, is usually about $\frac{1}{16}$ th of an inch in thickness; but this is by no means the utmost degree of thinness which it will bear. Its ductility and tenacity are rather low: a tin wire, $\frac{1}{16}$ th of an inch in diameter, is stated by Muschenbroeck (as quoted by Dr. Thomson) to be capable of supporting a weight of 31 lbs. only, without breaking. Tin may be easily bent, and when bent, produces a peculiar crackling noise: it fuses at about 442° of Fahrenheit's scale, but will bear a most intense heat before it is volatilized. On being exposed to the atmosphere, its surface becomes slightly tarnished, but it undergoes no other change. When kept under cold water it undergoes no change; but red-hot tin, exposed to the vapour of water, decomposes it, an oxyd of tin is formed, and hydrogen gas is evolved. Exposed to the action of the air in a melted state, it quickly becomes covered with a greyish powder, or oxyd; and if the heat is very violent, it is stated to take fire, and to burn with a pale white light.

Tin unites with oxygen in two proportions, as has been lately proved by Gay Lussac, in opposition to Berzelius, who concluded from his experiments that there were three oxyds of tin. (See *Annal. de Chimie et Phys.* vol. i. p. 40.) The first oxyd, or protoxyd, of tin, consists of about

Tin	-	-	100.
Oxygen	-	-	13.6

The second, or peroxyd, of about

Tin	-	-	100.
Oxygen	-	-	27.2

This gives the weight of the atom 7.352. Dr. Thomson is inclined to consider it as 7.375; but it perhaps will be found hereafter either 7.25 or 7.5. The first of these oxyds may be formed by dissolving tin in muriatic acid, either by means of heat, or by adding occasionally a little nitric acid: when dissolved, add to it a solution of potash; a white precipitate falls, which is partly taken up again; but the remainder, on standing, assumes a dark grey colour, and even a metallic lustre; and on being heated to whiteness, is pure protoxyd of tin. The peroxyd may be formed by

boiling the protoxyd in dilute nitric acid, drying by evaporation, and heating to redness.

Tin forms likewise two combinations with chlorine. When tin is burnt in chlorine, a very volatile clear liquor is formed, a non-conductor of electricity, and which, when mixed with a little water, becomes a solid crystalline substance, a true muriate of tin, containing the peroxyd of tin. This compound has been called the *smoking liquor of Libavius*, from its discoverer, who formed it by distilling together amalgam of tin and corrosive sublimate. According to the experiments of Dr. John Davy, it consists of two atoms or proportions of chlorine united to one of tin; or of about

Tin	-	100.
Chlorine	-	121.82

Prochloride of tin, first described by Dr. J. Davy, is a grey, semi-transparent, crystalline solid, and may be formed by heating together amalgam of tin and calomel. According to the same chemist, it consists of one atom or proportion of chlorine united to one of tin; or of about

Tin	-	100.
Chlorine	-	60.72

Tin combines readily with sulphur and phosphorus, but not with hydrogen, azote, carbon, or boron.

There are two sulphurets of tin; the first may be formed by fusing tin and sulphur together: it is of a blueish colour, and lamellated structure; and from the experiments of Dr. J. Davy, consists of one proportion of tin united to one of sulphur. The other sulphuret of tin is made by heating together the peroxyd of tin and sulphur. It is of a beautiful gold colour, and appears in fine flakes. It was formerly called *aurum musivum*, and various complicated processes given for forming it. Pelletier and Proust investigated its nature, and concluded it to be a compound of oxyd of tin and sulphur; but Dr. Davy has shewn that this is not the case, and that it consists merely of one proportion of metallic tin united to one proportion of sulphur.

The phosphuret of tin may be formed by heating the two substances together. Only one phosphuret is known: it has a metallic appearance, and is so soft that it may be cut with a knife. When gently heated in the air, the phosphorus takes fire. According to the experiments of sir H. Davy, it contains about 17 per cent. of phosphorus, and consists therefore of one atom or proportion of phosphorus united to one of tin.

Tin combines with most of the metals, and some of its alloys are much employed.

Its alloys with the metals of the fixed alkalies speedily tarnish in the air, and effervesce in water.

It readily unites with gold by fusion, and was formerly supposed to have the property of rendering this metal brittle; but this has been more recently denied. An alloy of 11 gold and 1 of tin, was found by Mr. Hatchett to have a pale whitish colour, brittle when thick, but when cut thin, capable of being bent easily. Its fracture was fine-grained, and of an earthy appearance. Mr. Alchorne found, that gold alloyed with no more than $\frac{1}{3}$ th of tin, retains its ductility sufficiently to be rolled and stamped in the usual manner. But Mr. Tillet shewed, that when heated to redness, the tin melts, and the alloy falls to pieces.

Its alloys with platina, according to Dr. Lewis, are brittle and dark-coloured, when the two metals are in equal proportions. The alloys of tin and silver are very hard and brittle. The alloys, or rather amalgams, of tin and mer-

cury differ in hardness, according to the proportions in which the two metals are mixed: three parts of mercury and one of tin form an amalgam which crystallizes in cubes, or, according to Sage, in the form of brilliant square plates, thin towards the edges. Tin readily combines with copper, and forms alloys exceedingly useful for a variety of purposes, as will be briefly noticed when we speak of the uses of this metal. Tin does not readily combine with iron, but their union may be effected by fusing them together in close vessels: it combines with zinc by fusion, and the alloy is harder than zinc, and stronger than tin: with lead it readily unites in all proportions, and the lead by the addition becomes considerably harder.

The oxyds of tin are capable of combining with the alkalies, and of forming with them peculiar compounds.

Salts of Tin.—Tin is oxydated and dissolved by many of the acids, and forms salts, differing in their nature according to the degree of oxydizement of the metal.

Nitrates of Tin.—Concentrated nitric acid (specific gravity 1.48) poured on tin, exerts but little action upon it; but if a little water be added, a violent action is exerted, and peroxyd of tin is formed, which separates in the form of a white powder, this oxyd being apparently incapable of combining with nitric acid: in this case, both the acid and the water are decomposed, and nitrate of ammonia is formed; but if the acid be diluted, and care be taken to moderate its action upon the metal, the water only is chiefly decomposed, and the protoxyd of tin is formed, which combining with the nitric acid, forms a solution of a yellow colour, which is a real nitrate of tin. Still, however, a little nitrate of ammonia is formed, and the nitrate of tin itself is not permanent, the metal continuing to pass to the state of peroxyd, and gradually separating. The same change is produced by heating the solution, a precipitate being deposited, which, however, is partly subnitrate of tin.

Muriates of Tin.—We have already spoken of the chlorides, or compounds of tin with chlorine. Now if water be added to these chlorides, they are converted into muriates of tin. The muriate of tin, in which the metal is in the state of protoxyd, may be formed, however, by dissolving tin in about four times its weight of muriatic acid: hydrogen escapes, and the solution has a brownish-yellow colour, and yields, on evaporation, small needle-shaped crystals, soluble in water, and somewhat deliquescent. Water poured upon it in small quantity decomposes it, and converts it into a submuriate, which is precipitated, and a super-muriate, which remains in solution. A similar effect is produced by the alkalies, when not added in excess. This muriate of tin, formed of the protoxyd, has a great tendency to combine with oxygen, and to pass into the state of muriates with the peroxyd, and this property enables it to exert many curious efforts upon other metallic salts. Thus, for example, the red oxyd of mercury, the black oxyd of manganese, the white oxyd of antimony, the oxyds of zinc and silver, are deprived of their oxygen by this salt, and reduced to the metallic state. The muriate of tin with the peroxyd of the metal may be formed as before mentioned. It is capable of crystallizing, and possesses properties quite different from those of the muriate above described. It is much used by dyers, who generally form it by dissolving tin in nitro-muriatic acid.

Sulphate of Tin.—Sulphuric acid, when cold, has little action on tin, but assisted by a moderate heat, it attracts oxygen from it; sulphurous acid gas is evolved, and a sulphate of tin is formed, which yields, when evaporated, small needle-formed crystals. It is probable there are two

sulphates of tin, though their properties do not appear hitherto to have been distinctly defined.

The *phosphate*, *fluat*, and *borat* of tin may be formed by double decomposition, by adding solutions of their alkaline salts to a solution of muriate of tin. They are all insoluble compounds, and have been but imperfectly examined. No *carbonate* of tin appears to exist.

The other salts of tin are unimportant, and but little known. The *acetate* has been most investigated: it may be formed by boiling tin in acetic acid. The solution has a whitish colour, and yields crystals by evaporation. There appears, however, to be another *acetate*, (formed probably with the peroxyd of the metal,) that does not crystallize, but is capable of existing only, on evaporation, in the form of a gummy mass.

Uses of Tin and its Compounds.—Tin and its compounds are extensively used in the arts. We shall here briefly point out some of the more important operations in which they are concerned, referring our readers for further particulars to the different articles themselves. An amalgam of tin and mercury forms the metallic coat of glass mirrors. For the method of performing this operation, see the article *SILVERING of Mirrors*.

The compounds of tin with copper are very important. Of this alloy *cannons* are made, also *bell-metal*, *bronze*, and the *mirrors* or *specula* of *telescopes*. For these different purposes, the two metals are mixed in different proportions, which are pointed out more particularly under their respective articles.

Vessels of copper, especially for culinary purposes, are usually covered with a thin coating of tin, to prevent the copper from oxydating. (See the article *TINNING*.) Thin iron plates covered with this metal, form what is known by the name of *tin-plate*; which see.

The oxyd of tin, mixed with that of lead, forms *putty*, which is much used in polishing metals. See *PUTTY* and *SPECULUM*.

Tin alloyed with lead forms *folder*; which see.

Of the salts of tin, a solution of the *muriate*, or *dyers' liquor*, as it is termed, is used as a mordant in dyeing *scarlet*. See the articles *DYEING*, *MORDANT*, and *RED*.

The solution of tin in aqua regia, added to the tinctures of cochineal, of gum-lac, and of some other red tinctures, heightens the colour of these, and changes it from a crimson or purple to a vivid reddish-yellow, or fire-coloured scarlet. The new scarlet, or Bow dye, is obtained in this manner; and it is said, that our most beautiful and lasting-coloured fine cloths owe their superlative excellence to the retentiveness given by our fine grain-tin; inasmuch, that the English superfine broad-cloths, dyed in grain by the help of this ingredient, are become famous in all markets of the known world.

Mr. Pryce apprehends, that the purple dye of the Tyrians owed its reputation wholly, or in part, to the use of our tin in the composition of their dye-stuff, as the tin-trade was solely under their own direction.

This colour, however, succeeds only with wool and other animal matters. Attempts have been made, but without success, to give this colour to thread, to cotton, and even to silk, though this latter substance has many properties of animal matters. The solution of tin made with marine acid alone, or with vitriolic acid, does only give to red tinctures a crimson colour, as alum does. Vegetable acids, as vinegar and cream of tartar, are also capable of dissolving tin.

Tin or its compounds are not used in medicine. They do not appear to be of a poisonous nature; but the muriate of tin, taken into the stomach in considerable quantity, speedily induces death, apparently merely from its corrosive qualities.

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It was formerly recommended for its anthelmintic virtues; but it is possible, says Dr. Lewis, that these may proceed not so much from the pure metal, as from a certain substance of a different or arfenical nature, of which the purest sorts of tin are found to participate.

The principal preparations of tin are as follow:

TIN, Butter of, is a name given by some chemists to a combination of tin with the concentrated marine acid of corrosive sublimate. It is procured by reducing these substances into small parts, and mixing them together: this mixture will, by degrees, be moistened by attracting the humidity of the air. The decomposition of the corrosive sublimate by the tin is more speedily effected by distillation.

TIN, Calx of, is the metal reduced into powder, either by means of fire, or by being dissolved in an acid menstruum, and precipitated with an alkali.

TIN, Crusts of. See *SPANISH WHITE*.

TIN, Diaphoretic of. See *ANTIHECTICUM POTERII*.

TIN, Flowers of, are a kind of white cosmetic, or paint for the complexion, drawn from tin with sal ammoniac, by means of sublimation.

TIN, Gold-coloured preparation of, is made by adding six ounces of mercury to twelve of melted tin, pulverizing the cold mass, mixing with it seven ounces of flowers of sulphur and six of sal ammoniac, and subliming in a matrass.

This preparation is called *aurum mosaicum*, and as a medicine is little regarded, though formerly much esteemed against hysterical and hypochondriacal complaints, malignant fevers, and venereal disorders. Upon experiment, it appears to be little more than calx of tin.

TIN, Salt of, Sal Jovis, is prepared from twelve ounces of calx of tin, and four of aqua regia, diluted with twenty-four of water: after digestion for two days, the vessel is to be shaken, the more ponderous part of the calx suffered to settle, the turbid liquor poured off, and evaporated almost to dryness, and the mass farther elicated on brown paper: to the remaining calx half the quantity of fresh menstruum is to be added, and the process repeated. Dr. Lewis's experience has not enabled him to pronounce on the virtues of this salt, which is in taste very sharp and corrosive: he thinks it needless to calcine the metal, as tin uncalcined dissolves much more easily and plentifully, and the solution is in both cases the same. According to Hoffmann, the solution of tin is a strong purgative. Lewis's Mat. Med.

TIN is also a word used by some of the chemical writers to express sulphur.

TIN-Coping, in *Rural Economy*, a sort of covering of this kind of metallic substance in the sheet form, which is not unfrequently employed on the upper parts of the frames, stands, or staddles of corn-stacks, for the purpose of preventing destructive vermin from entering or getting into them. It is a cheap, ready, convenient, and useful material in this intention, in many cases, which the arable farmer should not be inattentive to in his stack-yard.

TIN-Floors, a contrivance used by our husbandmen who propagate hops, to dry them after the gathering. See *OOST*.

It is thus done: Let a square brick room be built, with a door on one side, and a long fire-place of a foot wide in the middle, reaching almost across it; let holes be made at the sides of this fire-place, to let out the heat into the room; and at the height of five feet above this, let a floor be made of laths of an inch thick, laid lattice-wise. Let this be covered with great plates of double tin, taking care that the joinings of the tin be well foldered, and lie upon the laths, nor over the interstices, which may be about four inches wide. Let a row of boards be fitted round the edge of

this floor, to keep the hops from falling off; then lay on a covering of hops of a foot thick, and make a small fire of charcoal in the mouth of the fire-place, and the hops will dry very quickly and very regularly. They may be continually stirred about while drying, and, when dry, a part of the boarded edge of the kiln may be taken down, and the dried parcel thrust out, and a fresh parcel laid on in their place. A very small quantity of fuel is sufficient in this way, and any fuel will do, for the smoke never comes at the hops. There is a very great improvement still upon this method of drying hops, used by some people: this is the making of a wooden cover, of the size of the tin-floor; this is covered with plates of tin nailed on, and is suspended over the kiln in such a manner, that it may be let down at pleasure, when the lower parts of the hops are dry. This is to be let down within ten inches of their surface, and there it acts as a reverberatory, and drives back the heat on the upper ones, so that they are dried as soon as the lower ones. Thus all the trouble of turning is saved, and the hops are much better dried than in any other way. Mortimer's Husbandry, p. 186. See VENTILATOR.

TIN-Foil. See FOIL, FOLIATING, and LOOKING-GLASS.

TIN-Hatch, in Mining, a term used by the people of Cornwall, to express the opening into a tin-mine. They also call it *tin-shaft*.

They make several openings in the sides of the hills where they expect veins of ore to be. All these, except that which opens on the head of the mine, are called *essay-hatches*; but that which does so, is made their entrance afterwards, and changes its name to that of the tin-hatch. See HATCHES and SHAFT.

TIN-Hoop for Cheese, in *Rural Economy*, a light thin hoop constructed of this sort of sheet metallic substance, that is sometimes employed in cheese-making, for holding and keeping the curd together while it is breaking and being crumbled down into the filling-vat, in order to prevent the trouble of raising and holding up the corners of the cloth which is made use of in the business. It is usually about nine inches in breadth, and formed so as exactly to fit the top part of the cheese-vat on which it rests when used. These hoops are sometimes made of other materials, as wood, &c. and are useful in saving time and trouble.

TIN-Ore, called *tin-stuff* by the miners in Cornwall. See TIN-Stone.

M. Gellert directs, that ores of tin should be assayed in the following manner: Mix a quintal of tin-ore, washed, pulverized, and twice roasted, with half a quintal of calcined borax, and half a quintal of pulverized pitch; these are to be put into a crucible, moistened with charcoal-dust and water, and the crucible placed in an air-furnace: after the pitch is burnt, give a violent fire during a quarter of an hour, and then withdraw the crucible. If the ore be not very well washed from the earthy matter, as it ought to be, a larger quantity of borax is requisite, with some powdered glass, by which the too quick fusion of the borax is retarded, and the precipitation of the earthy matter is prevented. If the ore contains iron, to the above mixture may be added some alkaline salt. See MOON-Stone.

The method of assaying tin-ore, says Mr. Pryce, is very easy; for in its form and size of black tin (which is the ore dressed by stamping, several washings, and calcination, if mineralized with vitriolic, arsenical, or sulphureous pyrites) great part of the work is done, and little more remains than fusion, which is accomplished by a red heat in the following process: Take four or five ounces of black tin as emptied from the sacks, mix it well with about one-fifth part of its weight of powdered culm; put the mixture in a black-lead

crucible, on the wind furnace, and, in about twenty minutes, the metal will be found precipitated to the bottom of the crucible, the culm and scoria floating on the tin. On the surface of this matter there will be globules of tin; and therefore the mixture should be stirred with an iron rod, to make them fall into the tin at the bottom. Close the furnace, and let the whole remain in fusion from three to five minutes. Keep in readiness an iron or brass mortar, and an ingot-mould about six inches long; pour the tin into the ingot, and empty the culm and scoria into the mortar, scraping off what remains in and about the crucible with a sharp iron. As soon as cold, put them into another mortar, and pulverize them gently, so as to separate the scoria from the largest of the globules of tin. Select the larger globules, and pulverize the remainder a second time; then put this stuff, twice powdered, on a shovel, and passing it often through water, in the same manner as the lighter parts are washed from ores in vanning, and the smaller globules will remain on the shovel; and these, with the larger (both together being generally called *pillion-tin*), being added to, and weighed with the ingot, shew the produce in metal of the four or five ounces assayed. See Macquer's Chem. Dict.; and Pryce's Min. Corn. p. 269.

TIN-Plates, an article of manufacture very common among us, and vulgarly called *tin*. It is iron plated over with tin. The French call it *fer blanc*, white iron, as we sometimes do in England. It was once known under a distinct name, *latten*, under which article the process of manufacturing it is described.

The process used for this purpose near Caermarthen, in South Wales, which is described by Mr. Donovan, in his "Descriptive Excursions through South Wales in 1805," is as follows:

The iron-ore employed in this manufactory is the common kind of the country, intermixed with a large portion of the fine hematite from Ulverston, in Lancashire, which gives a very fine metal. This too is smelted with charcoal instead of coke, to produce a metal of the greatest purity and extensibility, and closeness of texture, which qualities are particularly required in this manufacture. The reduced ore is smelted in the usual manner, and cast into pigs, which are then wrought by the hammer into long flat bars, that are afterwards cut into pieces of about ten inches in length. These are then wrought into plates by being heated red-hot, and passed through a flattening-mill, which consists of two large cylinders of steel, case-hardened and secured in a frame of iron. These are placed contiguous to each other, but with a certain interval of space, and revolve in a contrary direction, so that when one end of the bar is thrust in the space between the cylinders, the whole is drawn through and proportionably extended and flattened in the passage. The distance between the cylinders, which of course determines the thickness of the plate, is maintained and regulated by screws which can be altered at pleasure. When the bar is thus made into a plate of twice the thickness of the ordinary plates, it is heated red-hot, cut in two by a pair of shears, and one piece folded exactly over the other, and both repeated through the cylinders till the folded plate has extended to the same length and breadth as the plate was before cutting. It is then clipped round the edges, and the two plates torn asunder (which requires some little force) after which they are each finished by passing through a finer rolling-press, so as to take away every crease or inequality in the plate, and those that are too rough to pass through this finer press are thrown aside.

The plates are then steeped in a very weak acid liquor, and when taken out are scoured thoroughly with bran, so as

to be quite bright and polished to enable the tin to adhere. The tin is melted in deep rectangular crucibles, and kept fluid by a moderate charcoal fire beneath. To prevent its calcination, a quantity of grease prepared from linseed-oil and suet is constantly kept floating on the surface of the tin, and renewed as it evaporates off, which gives an excessively nauseous stench. The plate is then taken up by one corner by a pair of pincers, and dipped vertically into the tin, and when withdrawn is found beautifully white and resplendent with the coating of this metal that adheres to it. This dipping is repeated three times for what is called *single tin-plate*, and six times for the *double plate*. The plates are then only cleansed and sorted, and are fit for use.

We shall here add, with regard to the history of this ma-

nufacture, that in the year 1681, tin-plates were made in England by one Andrew Yarranton, who was sent to Bohemia to learn the manner of making them. But the manufacture was discontinued by his employers, and afterwards so much disregarded, as to be reckoned among the projects called bubbles of the year 1720; however, it was revived, and brought to such perfection about the year 1740, that very little of it was imported from foreign parts; our own plates being of a finer gloss, or coat, than that made beyond sea, the latter being hammered, and ours being drawn under a rolling-mill. And. Hist. Com. vol. ii. p. 175, 361.

The two principal wholesale houses for this manufacture in London, are those of Jones and Taylor in Tottenham-Court Road, and Howard and Co., in Old-street Road.

Tools

TOOLS, simple and popular instruments, used in the more obvious operations, and particularly in the making of other more complex instruments.

The term *tool* is particularly used by canal-makers, for a kind of strong curved spade or shovel employed in canal-works.

Tools are divided into *edge-tools*, *spring-tools*, *pointed-tools*, &c.

Mr. Parkes, in the fourth volume of his "Chemical Essays," has given a history of the origin and progressive improvement of edge-tools, and an account of the materials of which they were constructed. It appears from Goguet's "Origin of Laws," to which he refers, that as many of the ancient nations had no knowledge of iron, they used stones, flints, the horns and bones of various animals, the bones and shells of fish, reeds, and thorns for every purpose in which the moderns now use edge-tools of iron and steel. Spears and other instruments for exterminating wild beasts, and even implements of agriculture, were formerly made with gold and silver; and instead of these was afterwards substituted copper, as a metal more easily to be procured than malleable iron. The abundance of celts and other ancient instruments, found in various parts of the globe, shews that copper and brass were formerly in very general use. From the prodigious number of copper instruments of different kinds and sizes, which have been found in this

country, such as axes, swords, spear-heads, arrow-heads, &c. known among antiquaries by the general name of celts, it is evident that our ancestors were well acquainted with the art of forming metallic copper in any way which they thought proper; whereas the use of metallic iron is comparatively of late introduction. At the time of the first Roman invasion, this metal was so rare, that the Britons fabricated their money with it, and even their ornamental trinkets. But the Romans having made themselves masters of the country, established imperial founderies for making iron, and constructed forges for manufacturing spears, lances, battle-axes, and implements of every kind, in different parts of the kingdom. (See Cæsar, de Bell. Gall. lib. v. c. 12. Henry's Hist. of Britain, vol. ii. p. 139, 140.) At the battle of Hamilton, in 1402, the repulse of the Scots appears to have been entirely owing to the excellent temper of the arrows which were employed by the English army. Swords also were then in use, and Sheffield was, even then, famous for its cutlery. Table-knives, it is said, were first made in London in 1563, by one Thomas Matthews of Fleet-bridge.

Good edge-tools cannot be made without steel; and of this there are various sorts (see STEEL); such as blistered, shear, spur, star, and cast steel; besides which there is a kind of German steel, made immediately from the iron ore, by simple fusions. (See also WOOTZ.) The cheapest

edge-tools, and other less important articles, are usually made with the first-mentioned kind, united to a large proportion of bar-iron. Clothiers' shears, firmer chisels, plane-irons, coopers' adzes, scythes, reaping-hooks, and large knives, are commonly made with shear-steel: for the method of manufacturing it, see STEEL. The spur and star steel are used only for particular purposes, according to the fancy of the master cutler. Cast-steel is used for the best penknives, scissars, and razors; and fine saws, surgical instruments, and all edge-tools which require a fine polish, and various other implements employed in cutting iron, are all made with cast-steel. The superior beauty of instruments made with cast-steel would have occasioned a very great consumption of this article, if it had not been for the difficulty of welding, or uniting it properly with iron, and which occasioned its being used at first only for those smaller instruments, such as lancets and penknives, which are generally made entirely of steel. But since the discovery made by Sir Thomas Frankland (for which see WELDING), cast-steel has been brought into more extensive use, and the instruments that are thus constructed, are much better than those which are made entirely of cast-steel. The circumstance of an instrument having its back made of iron, renders it not so apt to fly from the work to which the edge or steel part is applied, and eventually less liable to break.

Many artists, long after the invention of cast-steel, used to unite it to the iron by means of rivets. Hoes are still made by riveting or screwing the back, together with the eye, upon a blade made with cast-steel. We cannot minutely recite the various manipulations that are practised in the manufacture of different edge-tools. The reader will find information of a more ample kind in the work of Mr. Parkes, above cited. (See also our article CUTLERY.) We shall, however, select the following particulars: the cooper's adze and the carpenter's axe are first formed by the white-smith, in iron, together with the eye for the helve. The instrument is then heated again, and the edge of the cutting part is slit down with a chisel, and this slit is filled with a thin piece of steel, of a corresponding size and form. The iron, that has been slit upon, is folded down upon the steel, and the whole again heated to a welding heat, when the sledge-hammer quickly unites the iron and the steel into one compact mass. Scythes and such other large instruments are forged at the mill, by means of a large hammer, moved

by water, and the process is called "skelping." Augers, gouges, large chisels, table-knives, razors, and other instruments of a similar bulk, are forged upon a large anvil by the principal workman, aided by an assistant called the "striker," who strikes occasionally with a sledge-hammer. Penknives, lancets, graters, surgical instruments, and other small edge-tools, are generally forged on a small anvil firmly fixed within a large one, in order to give greater steadiness. These are usually fashioned out of steel only, and forged by one workman singly and alone. Scissars are also forged by a single hand; but the anvil on which they are fashioned is of a peculiar construction, having *bosses* or *dies*, and *beak* irons of various sizes occasionally adapted to it, so as to suit the different shapes and dimensions of the separate parts of these particular instruments.

It should have been noticed, that many other tools besides the axe and the adze are originally forged out of a piece of iron, with a little steel welded to it for the cutting part of the instrument.

The real Damascus sword-blades are said to be composed of slips or thin rods of iron and steel bound together with iron wire, and then firmly cemented together by welding.

It is well known that it is the circumstance of drawing down the shear-steel under the tilt-hammer that gives it the superiority over common steel. (See *Tilt-Hammer*, and *TILTING of Steel*.) Mr. Bingley therefore suggests in his patent, that, if he could roll out his steel much thinner than it had ever been done before, he should much improve its quality: and accordingly a very thin piece of steel is let into the face of a plane-iron made of cast-iron; and, as the steel for this particular purpose has to go through the rollers several times to make it sufficiently thin, it becomes of a peculiar texture, and the tool made with it is found to suit the joiner much better than the plane-irons heretofore in use.

In the manufacture of edge-tools, the process which immediately succeeds the forging is that of *hardening*. All these cutting instruments are therefore fashioned when the metal is in its original soft state; and when they have attained the intended forms, they are heated afresh to a particular temperature suitable to the article. When they have acquired that degree of heat, they are instantly plunged into cold water, which gives them great hardness, and renders them capable of cutting soft iron, or even steel. See TEMPERING.

Turning

TURNING, in the *Mechanical Arts*, is the operation of shaping wood, metal, or other hard substances, into a round or oval figure, by the aid of a machine called a *lathe*; which see.

In turning, the work or substance to be operated upon is placed in the lathe, and made to revolve with a circular motion about a fixed right line as an axis of motion; and the exterior surface is worked to its intended figure by means of some kind of edged tool, which is presented to it and held fast down upon a fixed rest. The protuberant parts of the work, by its rotatory motion, are carried against the cutting edge, and cut off, so as to reduce every part of the outside surface, to an equal distance from the axis of motion, and of course it will be of a circular figure.

The articles which admit of being turned to give them their figure, are all such as combine the three following properties: 1. That they may be supposed to have an imaginary right line or axis passing centrically through the whole length of the piece: 2. That all the sections which can be made by planes perpendicular to such axis shall be circular:

and 3. That the centre of all such circles shall coincide with the axis or centre line.

It should be observed, that a piece of work may have two or more centre lines in different parts or in different directions; but it must in that case be formed or turned at two or more successive operations, because what can be done at once fixing in the lathe, must come within the above definition.

The work may be turned hollow, so as to make a cavity within; or work may be turned on the outside, to give form to the external surface; and frequently work is turned both without and within; but in either case, the above definitions will apply.

Diodorus Siculus says, the inventor of the art of turning was a nephew of Dædalus, named Talus; and that the reputation which he acquired by this invention excited the jealousy of Dædalus, and induced him to put Talus secretly to death. Pliny ascribes it to Theodore of Samos, and mentions one Thericles, who rendered himself very famous by his dexterity in managing the lathe. With this instrument,

ment, it is said, the ancients turned all sorts and kinds of vases, many of which they enriched with figures and ornaments in basso relievo. Thus Virgil says:

"Lenta quibus torno facili superaddita vitis."

The Greek and Latin authors make frequent mention of the lathe, and Cicero calls the workmen who used it, *vascularii*. It was a proverb among the ancients, to say a thing was formed in the lathe, to express its delicacy and justness.

The art of turning is of considerable importance, as it contributes essentially to the perfection of many other arts. The architect uses it for many ornaments, both within and without highly finished houses. The mathematician, the astronomer, and the natural philosopher, have recourse to it, not only to embellish their instruments, but also to give them the necessary dimensions and precision: in short, it is an art absolutely necessary to the mechanist, the goldsmith, the watchmaker, the joiner, the smith, and others.

As the operation of turning is to be performed by the aid of the lathe, the structure of that machine is the first thing to be considered. In our article *LATHE*, we have given a description of the most perfect kind of lathe, made in iron, with a triangular bar; and in the article *ROSE-ENGINE*, we have described a curious lathe for ornamental turning; but it is to be observed, that a much more simple machine will answer all the common purposes of turning.

The essential properties of a lathe for *outside* work are, first, that it shall have two points which will firmly sustain the work at each end, by penetrating into the ends of the work, and, at the same time, allow it to turn freely round upon the points: there must be a rest or support to hold the tool upon, and also some means of turning the work round upon the points. A lathe to turn hollow or *inside* work will not admit of a point of support at each end of the piece, and therefore the work is firmly fixed to the extremity of a spindle, which is called a *mandrel*; when the mandrel is turned round, the work revolves with it, and the tool can be applied at the end of the work, to excavate or turn it hollow within, or to turn it on the outside, as required.

Lathes are made in a great variety of forms, and put in motion by different means: they are called *centre lathes*, where the work is supported at both ends; and *mandrel, spindle, or chuck lathes*, when the work is fixed at the projecting extremity of a spindle.

From the different methods of putting them in motion, they are called *pole lathes*, and *hand-wheel lathes*, or *foot-wheel lathes*. For very powerful works, lathes are turned by horses, steam-engines, or water-wheels.

The lathes used by wood-turners are generally made of wood, in a simple form, and are called *bed lathes*: the same kind will serve for the common turning of iron or steel, but the best work in metal is always done in iron lathes, which are sometimes made with a triangular bar, and are called *bar lathes*, (such an one is described in the article *LATHE*); small ones, for the use of watch-makers, are called *turn-benches*, and *turns*; but there is, in fact, no proper distinction between these and the centre lathes, except in regard to size, and that they are made of iron and brass instead of wood.

The *centre lathe* is the most simple of all others. Two beams of wood are fixed horizontally upon legs, like a bench, and form what is called the *bed*. The two beams are fixed together, parallel to each other, and at a small distance asunder, so as to leave a space or narrow groove between them, nearly the whole length of the bed. This groove is to receive the *tenons* at the lower ends of the *puppets*, which are short posts rising perpendicularly from the bed, and firmly fixed thereto

by means of cross wedges, put through the tenons beneath the bed; for the tenons are of sufficient length to descend quite through the groove in the bed, and project beneath sufficiently to receive the cross wedges, which being driven in, draw the bases of the puppets or posts so firmly down upon the surface of the bed, that they will stand firmly erect upon it; or by withdrawing the wedges, the puppets become loose, and can be fixed in another part of the bed, in order that the distance between the two puppets may be made to correspond with the length of the piece of work to be turned. One of the puppets has a pin or *pike* of iron fixed into it, and the other one has at the same level the centre *screw*, working through a nut fastened in the puppet: both the screw and pike have sharp points made of steel, hardened and tempered, that they may not wear away. They must be exactly opposite, and in a line with each other. The piece of work, suppose for instance it is a roller of wood, is supported by its ends between the points of the pike and the screw, that it may turn round freely. The *rest* for the support of the tool is a rail or bar, extending from one puppet to the other; it lies in hooks, projecting from the faces of the puppets.

The work is put in motion by means of the *treadle*, which is worked by the turner's foot; a *string* or catgut is fastened to the treadle, and passing two or three turns round the work, it is fastened to the end of an elastic *pole*, fixed to the ceiling over the turner's head.

The workman stands before his lathe, having one of his feet on the treadle to give it motion; he places a sharp *gouge* or *chisel* on the rest, and approaches the edge of it gently to the piece of work; then pressing the treadle down by his foot, the string turns the work round, and the chisel or gouge being held firm upon the rest, and so as to touch the wood, it will cut it to a circular form. When he has brought the treadle to the ground, he releases the weight of his foot, and the elasticity of the pole draws up the treadle, turning the work back again; during which retrograde motion, he withdraws the chisel from the work, as it would not cut in this direction, though it might impede the motion of the wood, and would injure the edge of the tool. He must perform his work gradually, without leaving ridges; and when he meets with a knot in the wood, he must go on still more gently, otherwise he would be in danger both of splitting his work and breaking the edge of his tool. For turning light work, a bow, such as is used for shooting arrows, is suspended by its middle over the lathe; the string is then tied to the middle of the bow-string, in lieu of the pole, and acts in the same manner.

The common centre lathe is a very imperfect machine, when worked in this manner; yet its simplicity is a great recommendation, especially among country workmen, who use it to make various sorts of common articles of household furniture in soft wood, as stool and table legs, stair-case rails, &c.

In centre lathes, the work is sometimes put in motion by means of a large wheel, turned by one or more labourers; the wheel should be heavy, that its momentum may be sufficient to overcome any moderate obstacle in the work; and the frame in which it is mounted must be of sufficient weight to stand steady, and not be liable to move, by the exertions of the man turning it. An endless line is used, to communicate the motion of the wheel to the work; it passes round a groove in the circumference of the wheel, and after crossing, like a figure of 8, goes round a small pulley, fixed upon the work. By this means, when the great wheel is turned, it gives a rapid rotatory motion to the matter to be turned, and with a much greater power than can be obtained from the treadle, with the additional advantage of the work turning always
the

the same way round, so that the turner has no need to take his tool off the work.

The centre lathe will turn any kind of work which will admit of being supported at both ends; and it is used by mill-wrights and iron-founders, for turning mill-shafts, axles, rollers, and other iron-work. For such purposes, the lathe must be made exceedingly strong, and with nuts and screws to fasten the puppets down upon the bed, instead of wedges; the rest must be made in iron, with the requisite adjustments for placing it close to the work, at that part where it is required to be turned. To put the work in motion, the centre pin or point in one of the puppets is made to project considerably, and has a pulley fitted upon it, so that it can turn freely round upon the pin by means of an endless band or strap, which communicates the motion from a great wheel. In these large lathes for iron-work, the wheel is commonly turned by horses, or by a water-mill or steam-engine. From the pulley a pin projects in a direction parallel to the centre pin, and a piece of iron, called a *driver*, is screwed or clamped fast upon the end of the piece of work, so as to project from it sufficiently to be intercepted by the pin which is fastened into the pulley: by this means, the motion of the pulley is communicated to the work. The tools employed for turning iron and other metals are different from those used for wood, as we shall afterwards describe.

The *spindle* or *mandrel lathe* will turn hollow or internal work, and is equally well adapted to turn centre work as the centre lathe. In *Plate Turning*, fig. 1. we have given a representation of one of these, which is on a very good construction, made by Messrs. Holtzapfel and Deyerlien: it is put in motion by the foot, so that the turner has both his hands at liberty to direct the tools. A A are upright legs, to support the bed B, which consists of two pieces or bars of cast-iron, put together, and leaving a small crack between them: C D is a cast-iron frame, which is fastened down upon the bed B, and supports the spindle or mandrel *ab*: E is the back puppet, which is used to support one end of a piece of work, as is shewn in the figure at G, when the other end is fixed to the end of the mandrel, and turned round by it: the back puppet, E, has a cylindrical pin accurately fitted into it at the upper part, and the end of the pin is formed to a sharp conical point, proper to penetrate and support the end of the work: this point is called the *back centre*. A screw *e* is tapped into the puppet, so as to press on the opposite end of the pin, and force it towards the work; and there is likewise a clamp screw, E, at the top, to bind or fasten the pin into its socket. The back puppet is fastened down upon the bed, by means of a tenon entering into the groove, through the bed B, and a screw descends from the tenon quite through the bed, and projects beneath it: upon this screw a nut *g* is tapped, and by turning it, the shoulder of the puppet E is drawn down firmly upon the bed; but when the nut is loosened, the puppet can be slid along the bed to place it at any required distance from the end of the spindle, according to the length of the piece of work G. It is necessary that the point of the back centre should in all cases be precisely in the centre line of the axis of motion of the spindle *ab*; and for this purpose, the bed must be made very straight, and flat on the upper surface; the groove through it should also be perfectly straight and parallel, and the tenon at the lower end of the back puppet must be exactly fitted to the groove: the frame of the mandrel must be so fixed on the bed, that the centre line of the mandrel will be exactly parallel to the bed, and to the groove in the bed.

Mandrels are mounted in different ways, but they are always made of steel at the parts where they are supported

in the collars, which collars should be also made of steel, and hardened, so as to have little friction. The neck of a mandrel must be very accurately fitted into the collar, so as to have no shake or looseness, at the same time that it can turn round quite freely.

The neck at one end projects beyond the collar, and the projecting part is formed to a screw, for the purpose of fixing the work to it. A variety of pieces, called *chucks*, are fitted upon this screw, and each chuck is adapted to hold a different piece of work: the chucks screw up against a shoulder on the end of the mandrel, and by the motion of turning round in the direction in which the lathe works, the chuck screws itself fast on against the shoulder; but if the lathe is stopped, and the chuck is turned in the opposite direction, it will unscrew and come off, and a different chuck may be put on. In some lathes, the neck of the mandrel is perforated, and cut within side, with a female screw adapted to receive a male screw on the chuck: the effect is just the same as the above described. The opposite end of the mandrel to that on which the chucks are screwed, must be supported either by a point or in a collar. In general, the mandrel is made with a point at one end; and the other end, which has the screw to fix the work to it, is formed with a neck, proper to run in the collar, and with a shoulder on the neck, to stop the neck from going through the collar. The mandrel represented in the drawing has a neck and collar at each end, for a purpose which will be explained. When the mandrel is made with a pointed end, the point must be received in the end of a screw tapped through the part D of the frame of the mandrel, just in the place of the end *a* of the mandrel. By turning this screw, the mandrel can be adjusted to run very correctly in length; and to prevent the screw from turning back when the lathe is in motion, a nut is placed on the screw, beyond the part *d*: this causes such a pressure upon the threads of the screw, that it is in no danger of turning back, as it would otherwise do with rough work. The mandrel, by this means, runs very steadily and accurately in its bearings, and it is plain that any piece of work, which is firmly attached to the end of it by means of the screw before mentioned, may be turned by a tool held over the rest, in the same manner as if it were mounted between centres, but with the advantage that it be turned at the end, to make hollow work when required.

The mandrel is turned round by a band of catgut passing round the pulley *b*, and also round the large foot-wheel H, which is made of cast-iron, and fixed on the end of the axis I. This axis is bent in the middle, as in the figure, to form a crank, which crank is united, by an iron link K, to the treadle L, on which the workman presses his foot. This treadle is affixed by three rails to an axis M, on which the treadle moves. The wheel H is of considerable weight in the rim, and being fixed fast on the axis I, turns round with it: the momentum acquired by the wheel is the power that continues to turn the work while the crank and treadle are rising, and consequently while the workman exerts no power upon them.

When the crank has passed the vertical position, and begins to descend, the workman presses his foot upon the treadle, to give the wheel a sufficient impetus to continue its motion until it arrives at the same position again. The length of the iron link K, which connects the crank with the treadle, must be such, that when the crank is at the lowest position, the board L of the treadle, to which the link is hooked, should hang about two or three inches from the floor. To put the lathe in motion, the turner gives the wheel a small turn with his hands, till the crank rise to the highest, and

passes a little beyond it; then by a quick tread he brings the crank down again, putting the wheel in motion with a velocity that will carry it several revolutions: he must observe to begin his next tread just when the crank passes the highest point, and then it will continue running the same way with a tolerable regular motion, if he is punctual in the periods of his treads. The foot-wheel, by means of the band, causes the mandrel to revolve very rapidly, so that it will perform its work very quick, and the workman must acquire a habit of standing steady before his work, that he may not give his whole body a motion when his foot rises and falls with the treadle.

The rest N of this lathe is fixed on the bed of the lathe by its foot, which is divided in the manner of a fork, to receive a screw-bolt: this bolt passes down through the lathe-bed, and fastens the rest at any place along the bed, by a nut *k* beneath. The groove in the foot is for the purpose of allowing the rest to be moved to and from the centre of the work, to adjust it to the diameter of the work which is turning. The height of the rest is a matter of some importance in turning, and in some work it should be fixed higher than others; therefore the piece upon which the tool is laid, is made with a shank of the form of the letter T. This shank is a round pin, and is received into a socket in the foot of the rest, and can be held at any height by a clamp-screw. As the socket and shank are cylindrical, the edge of the T of the rest can be placed inclined to the axis of the work when turning cones, or other similar work, though the same purpose may be accomplished by the screw, which holds the foot of the rest down to the bed of the lathe, admitting the fork to stand in an oblique direction across the bed.

The wood-turner employs gouges of all sizes, and chisels of different forms: the gouges are used in the first instance to rough out and form the wood, as they cut very rapidly, because they can take a very strong chip, and the angles will not stick in, as would be the case with the chisels. The latter are used to smooth the work, and to reduce it exactly to shape and size.

The blade of the turning-gouge is formed nearly half round to an edge, and the two extreme ends of this edge are a little sloped off, in the manner of an apple-scoop, that the middle part of the edge may cut away the prominences of the work; and it has no corners, which would catch and get fast in the rough wood. The hollow part is whetted upon a piece of Turkey-stone, made with a convex edge, for the purpose; the outside is whetted upon a common flat Turkey-stone, taking care to turn the gouge round, that all parts of the convex edge may successively be sharpened. In turning, the blade of the gouge must be held considerably inclined, by depressing the handle (see *fig. 42.*), so that the bevel, or outside of the edge of the gouge, may come very nearly in the tangent to the circumference of the work, and the cutting edge be above the level of the centre. The turner holds the tool down firmly upon the rest, keeping it steady, by placing the long handle under his arm.

The turner's chisels are mostly ground with a bevel on both the flat sides, so that either side may be indifferently applied to the work: they are ground up and sharpened on the oil-stone to a keen edge. In some chisels, the line of the edge is inclined to the direction of the blade, instead of being perpendicularly across it, as in the chisels used by carpenters; in others, the edge is rounded to a semicircle, instead of being a straight line; and others are made with angular points, like spears. It is difficult to describe the proper use of each particular tool, as the turner must employ one or other, according to the

particular part of the work which is to be executed. In using the chisel, the rest is raised considerably above the centre of the work, so as to be nearly on a level with the top of it (see *fig. 41.*), and the line of the cutting edge must stand oblique to the axis of the cylinder, so as to prevent either angle of the chisel from running into the work. It is necessary to traverse the chisel gradually along the work, but not too fast, otherwise it will leave a roughness on the surface.

The turning-tools should be fixed in long handles, and the turner holds them firmly down upon the rest, steadying them by placing the end of the handle under his arm.

The turner should be provided with a grindstone, and an oil or Turkey-stone to sharpen his tools; and he must have callipers and gauges to ascertain the dimensions of his work. In order to fix the work in the lathe, he must have a great assortment of chucks. The chucks for wood-turning are blocks of wood, each having a screw, by which it can be attached to the mandrel. The end of the chuck being turned true, and the shoulder of the screw upon the mandrel being also turned true, the chuck fixes so tight to the spindle, that it becomes as it were one piece with it. Most of the wood chucks are bored out like a box, and the work is jammed into the cavity. There are other chucks, which are only flat round boards, and the work is cemented or screwed against them; but the generality of chucks are cylindrical blocks, with a cylindrical or conical hole turned in the end, like a box, into which the piece of wood to be turned is driven fast, so as to be turned round with the mandrel. The chucks are generally hooped with iron, to prevent them from splitting. When centre-work is to be turned in a mandrel lathe, a chuck must be screwed on the end of the mandrel, which terminates in a sharp conical point.

The lathe should be fixed in a place very well lighted; it should be immoveable, and neither too high nor too low.

The puppets should neither be so low as to oblige the workman to stoop in order to see his work properly, nor so high, that the little chips, which he is continually cutting off, should come into his eyes.

The piece of wood to be turned should be rounded, before it is put in the lathe, either with a small hatchet made for the purpose, or with a plane or rasp, fixing it in a vice, and shaving it down till it is every where almost of an equal thickness, leaving it a little bigger than it is intended to be when finished off. Before putting it in the lathe, it is also necessary to find the true centres of its two end surfaces, so that they shall be exactly opposite to each other, in order that, when the centre points of the puppets are applied to them, and the piece is put in motion, no one side may project out more from the centre line than another. To find these two centres, lay the piece of wood to be turned upon a plank, open a pair of compasses to almost half the thickness of the piece, lay one of the legs on the plank, and let the point of the other mark on one of the ends of the piece when laid flat on the plane with the plank, like a roller, from which plank the point of the compasses stands up at a given height above the plane on which the piece lies. Describe four marks or arcs on that end at equal distances from each other round the circumference of the end, by laying the piece successively on four different sides, which arcs intersecting one another, the point within the intersections will be the centre of the end. In the same manner, the centre of the other end must be found.

After finding the two centres, make a small hole at each of them, into which insert the centre points of the back centre and the mandrel, and screw up the back centre, to fix the

the piece so firmly as not to be shaken out, and yet loose enough to turn round without difficulty.

This is the manner of fixing the work when it is to be turned between centres; but if it is required to be hollowed out, the back puppet is removed, and the work must be fixed in a chuck at the extremity of the mandrel. For this purpose, a chuck is selected which has a hole in it nearly the size of the piece of wood, the diameter of which being taken in the callipers (*fig. 35.*), the chuck is screwed to the mandrel: the rest is fixed in a convenient position, and the hole in the chuck turned out by a proper tool to the size measured by the callipers: the hole should be rather conical, and the wood, being rasped to the same figure, is driven in fast by a hammer. By turning the mandrel slowly round, it will be seen if the wood is fixed straight in a line with the mandrel, and if not, a blow or two of the hammer, properly directed, will rectify it.

If the piece of wood is not very long, the chuck will be sufficient to hold it firm whilst it is turned; but if it is not, then a small centre hole must be made in the extreme end, and into this the point of the back centre screw must be inserted to steady the work, until the rough part of the turning is done, and then it may be removed; but it is much more convenient to turn without the back centre, and therefore the turner fits the chuck to the wood with care, so that it will fix fast in the chuck.

The work being thus chucked, or fixed in the lathe, the rest is set, so that its edge is close to that part of the work which is required to be turned, and the top of the rest being raised considerably above the level of the centre of the work, it is there screwed fast.

The turner now puts the lathe in motion by treading with his foot, and takes a gouge, of a proper size, in his right-hand, and holds it by the handle a little inclined, keeping the back of the hand lowermost: he grasps the blade of the tool with his left-hand, the back of which is to be turned upwards, and he holds it as near the end as possible on the front side of the rest; then leaning the gouge on the rest, he is to present the edge of it a little higher than the horizontal diameter of the piece, so as to form a kind of tangent to its circumference: see *fig. 42.* This is the best position for cutting, and the tool must be held very firmly, to prevent the edge being depressed by the motion of the work, for if it does, it will take hold too deep, and tear the work. The gouge is applied first to one end of the work, and gradually advanced to the other, turning the work true all the way, and reducing it till the callipers (*fig. 36.*) determine it to be near the intended diameter.

The chisel is next employed to smooth the cylinder: its handle is held in the right-hand, whilst the left grasps the blade, and keeps it steady upon the rest, holding the edge a little inclined over the work, as in *fig. 41*; so that one side of the flat part of the blade lies on the rest, and the other side is elevated, that the plane of the blade, and consequently the line of the edge, is not horizontal, but inclined thereto, so that one corner of the edge of the chisel is elevated above the work: then the bottom of the edge of the chisel, or near the bottom, cuts away a shaving from the work, and this is the only way in which it will cut; for if the edge of the chisel is held parallel to the axis of the cylinder, it acts parallel to the length of the grain of the wood, scraping away the fibres, one by one, without cutting, and leaves a very rough surface. In the same manner, the narrow chisels, formers, and other instruments, are to be used according to the work which is to be done, taking care that the wood be cut equally, and that the instrument be not pushed suddenly forwards, or sometimes more strongly than at others;

and taking care also that the instrument does not follow the work, but that it be kept firm on the rest, without yielding. The gouge and chisel are the instruments by far the most frequently used, and the most necessary in this art. Soft woods are almost entirely turned by them.

To make the end of the work exactly flat, the thin side of the chisel is laid upon the rest, so that the plane of the edge may stand exactly upright. The hand is depressed, that the lower corner of the edge may rise against the work, and cut a deep circle into it, near the end, and being steadily advanced, cut to the centre, separating a thin round chip, and leaving the end quite flat. The cutting corner of the chisel must be directed exactly perpendicular to the length of the work, in advancing it, otherwise the end will be either concave or convex, and care must be taken to keep the plane of the edge truly upright, and hold it very firm, for there is danger of the work drawing the chisel into the end of it, with a deep spiral cut, like a screw, and tearing the work out of the chuck.

A cylinder of wood being formed by the process we have just described, if it is required to turn it hollow within, the rest is fixed opposite the end of it, with the edge of the rest perpendicular to the length: then a sharp-pointed tool is used, to bore such a hollow in the end as will form the required cavity, using the inside callipers (*fig. 35.*) to determine the size of it. The side-tool, which is made with a cutting edge on the side, like a knife, may be used, if it is required to make the bottom of the cavity square; or a hooked tool, with the cutting edge at the end of the hook, may be employed to enlarge the inside to the proper size: the gauge (*fig. 34.*) is used to determine the depth to which it is to be turned.

This is the process for turning soft woods, which are generally of a fibrous texture: but hard woods, ivory, and bone, are turned with different tools. The points or cutting edges of some such tools are represented in *figs. 23.* and *24*; they are bevelled only on one side, and the angle of the edges is obtuse. The round-pointed tool, and the sharp angular-pointed tool, are those employed for first roughing out the work, and by them a number of contiguous grooves are cut in the wood, until its grain is broken and divided, and the irregularities reduced; then an edged tool can remove the remainder: but as the edged tools will only cut or scrape off thin shavings, they are not used when the work is to be reduced to size, but only to finish it. The manner of applying the tools to the work is shewn in *fig. 39.* and is nearly the same as for turning brass, or other soft metal: the upper surface of the tool is directed to the centre of the work, the intention being to scrape away shavings in hard wood, and in soft to cut chips, as at *figs. 41.* and *42.* The graver (*fig. 40.*) is a very useful tool for hard wood: the manner of using it, as well as other tools, will be described when we come to speak of turning in metal.

After the work is completely turned, it is next to be polished, and this cannot be done with the instruments hitherto mentioned. Soft woods, as pear-tree, hazel, maple, &c. ought to be polished with shark-skin, or Dutch rushes. There are different species of sharks, some of which have a greyish, others a reddish skin. Shark's skin is always better when it has been used; at first, it is too rough for fine polishing.

The Dutch rush is the *equisetum hyemale*; it grows in moist places, among mountains, and is a native of Scotland. The oldest plants are the best. Before using them, they should be moistened a little, otherwise they break in pieces almost directly, and render it exceedingly difficult to polish with them: they are particularly proper for smoothing the

hard woods, as box, *lignum vitae*, ebony, &c. After having polished the piece well by such means, it should be rubbed gently either with wax or olive-oil, then wiped clean, and rubbed with its own turnings or shavings, or with a cloth a little warm. Ivory or horn is polished with pumice-stone or chalk, finely pounded and put upon leather, or a linen cloth a little moistened with this: the piece is rubbed as it turns round in the lathe; and to prevent any dirt from adhering to any part of it, every now and then it is rubbed gently with a small brush dipped in water. To polish metals very finely, the workmen make use of a particular kind of earth called tripoli, and afterwards of putty, or calx of tin. Iron and steel are polished with very fine powder of emery; this is mixed with oil, and put between two pieces of tin or pewter, and then the iron is rubbed with it. Tin and silver are polished with a burnisher, and that kind of red stone called blood-stone. Iron and steel may also be polished with putty, putting it dry into shamoy-skin.

All kinds of articles in wood are turned in the above manner; but many contrivances are necessary to mount different things in the lathe.

The small figures in the plate represent various chucks, which are occasionally employed, and which are adapted for turning different kinds of work.

Figs. 2. and 3. exhibit a small wood chuck, which is adapted to be screwed to the mandrel at *a*, a hole being perforated in the centre of it, at *b*, into which a small piece of wood or ivory is to be inserted, in order to turn it. To hold the work fast in this chuck, it is divided at the end *b* by two saw-kerfs, at right angles to each other, as shewn in *fig. 3.* so as to separate the end into four segments, which admit of expanding or closing: a hoop or ferril is fitted on the outside of the chuck, which part is made tapering, so that forcing the ferril farther on, will close the four segments together, and bind fast upon the work, which is introduced into the cavity *b*. This is a very convenient chuck for holding small pieces of ivory, and particularly for the purpose of polishing.

Figs. 12. and 13. exhibit a similar chuck, made in brass, for more delicate work; it is only divided into two segments.

Fig. 4. is a brass box, to screw to the mandrel, and hold a wood chuck, such as we have before explained. Wood chucks are usually made to screw on the mandrel by means of a hole in the chuck, which is cut with a female screw within. The objection to this mode is, that the threads of the screw on the wood wear away by constant use. In *fig. 4.* a brass female screw, *a*, is cut to fit the screw of the mandrel, and at the other end, *b*, is a box, also cut with a screw within, into which the wood block or chuck is screwed, as shewn by the dotted lines, so as not to come out without great force: by this means, the fitting of the chucks to the mandrel is not with a wooden screw, as in general, but with a brass one, which will not be liable to get out of the truth, but will always screw up to the same shoulder. The lathe should have at least two dozen of these wood chucks, with cavities of different sizes, and some of them hooped with iron at the outer end, to prevent them splitting. The brass box is a great security against splitting.

Fig. 5. is a very useful arbor for turning wheels, collets, or any other flat piece of work that will admit of having a small hole in the centre of it. A brass screw-chuck, *a*, is fitted to the mandrel, and a steel pin, *b*, is fixed into it, and projects an inch or more: the pin is turned true, and the work is held fast upon it, either by turning the pin to the size, or by broaching the hole in the work: and to prevent the work from slipping round upon the pin, it is pinched fast up against the flat surface of the chuck, as shewn by the dotted lines, by a nut *d*, which is screwed on the end of the steel

pin *b*: by this means, the work will be held fast, and will be carried round by the chuck, so as to be turned by the application of proper tools upon the rest. These kinds of arbors should be of all sizes, to fit the holes in different wheels, &c.

Fig. 10. is a brass chuck, which is very useful for holding small pieces of brass work; it screws to the mandrel at the end *a*: the hollow part, *b b*, has six screws tapped through it, and pointing to the centre, as shewn in *fig. 11.* By screwing in these screws, their points will pinch upon any piece of work which is put into the chuck, as shewn at *d*, and will hold it firm. The screws being regulated, admit of adjusting the work *d* to a true centre with the line of the mandrel.

Figs. 16. and 17. are views of chucks having similar properties to the preceding: *a* (*fig. 16.*) is the end which is screwed to the mandrel; *b b* is a circle of brass, having a mortise or opening across the centre of it, as in *fig. 17*; into this opening two steel dies are fitted, and screws *d, d*, are placed behind them, to approach them together: the screws come through the outside of the chuck, and have square heads, which are to be turned by means of a key. The adjacent surfaces of the two dies are hollowed, so that they will embrace a piece of wire or other similar substance which is put between them, and the dies may be cut like a file, to hold it fast. By means of the two opposite screws *d, d*, the work may be adjusted to the centre line of the mandrel.

Figs. 20. and 21. are a table-chuck, proper for holding wheels or flat plates by the circumference, whilst the centre parts are turned: *a* is the screw to fix it to the mandrel: *b b*, a large circular plate, turned perfectly flat on the front surface. In this plate are grooves, pointing from the centre to the circumference, as shewn in *fig. 21*: the grooves are adapted to receive clamp-pieces, *d, d, d*, by means of which the wheel or other work is bound fast against the flat surface of the chuck. The grooves admit the clamps *d, d, d*, to be placed at any distance from the centre, according to the size of the work, and to place them at those parts where it will be most convenient to apply them.

The form of these clamps is shewn more particularly in *fig. 22*: *f* are sliders of metal, which are fitted to the grooves in the chuck; and the grooves are dove-tailed, so that these sliders can be put into the grooves at the back of the chuck, but will not draw through the grooves into the front. Screws are tapped into the sliders, and draw the clamps, *b*, against the face of the chuck, and hold fast the work, which is placed beneath their claws. The clamps, *b*, have flanks projecting from them at right angles, which pass through the grooves, and keep the clamp from turning round to one side.

Figs. 35. and 36. represent the callipers used by turners to take the measure of their work: they are made of two curved pieces of steel-plate, united together by a joint. When they are opened, as in *fig. 36*, the dimensions of a round piece of work may be conveniently taken between their points, as shewn by the dotted circle; but if the points are closed together, as in *fig. 35*, so that they pass each other, then the callipers are adapted for measuring the diameter of internal cavities, by the distances of their points from each other.

Several other kinds of callipers are used by turners, but these are the most convenient, as they serve equally well for inside and outside dimensions. Some callipers are made double, like a pair of scissars; and the points at one end are for inside measures, whilst the others are for outside measures; and the distances of all the points from the joint being exactly the same, the inside measure of any hollow

being taken by one end of the callipers, the opposite end will be readily opened to the requisite dimensions for a solid to fill such hollow.

Fig. 34. is a gauge for measuring the depth of hollow work. *A* is a ruler, through which is a socket to receive another ruler *B*; and a clamp-screw is fitted through the side of the socket, to hold the ruler, *B*, fast in the socket. The edge of the ruler, *A*, is applied to the end of the work, and the other ruler is then slid through its socket, until the end of *B* touches the bottom of the cavity; and in this state, the clamp-screw being fastened, the gauge may be applied to the piece of work in the lathe, to ascertain if the cavity is turned out to the required depth.

Fig. 6. is a chuck for turning wood when it is a long piece, which will admit of being supported at both ends, or between centres, as it is called. The chuck has a screw within the part *a*, to fix to the mandrel, and the other end is of steel, with a pin *b* in the centre; and on each side of the pin is a sharp edge *c*, like a chisel, the line of the edge pointing to the centre of the pin. When a piece of wood is mounted between the points of this centre pin and of the back centre, as we have before described, if the back centre screw is turned, it will force the piece of work against the mandrel and the pin *b*, and the edges *c* will penetrate into the opposite end of the wood; in this case, the motion of the mandrel and chuck *a* will be communicated to the wood, to turn it round. The centre pin *b* is made to project beyond the edges *c*, and by this means the work may be removed from the lathe, and put in again if required, because the centre pin will enter again into the same hole in the end of the work, and restore the work to its original position.

Fig. 7. is a chuck for the same purpose, but it is made with a flat circle of brass, and three pins, *c*, are fixed in it instead of the edges *c*, *c*. This kind of chuck is shewn in use in *fig. 1*, to turn a pillar for a balustrade.

When a piece of metal work is to be turned between centres, the edges or points of the last chucks cannot be made to penetrate the end of the piece, and therefore a small chuck, *b*, (*figs. 14.* and *15.*) is screwed to the mandrel: in the end of this chuck, at *b*, is a hole, which is made square within, and the work has a square filed at one end to fit the hole. The other end of the work is supported by the back centre, a small hole being made in the end to receive its point; or if the end of the work is sharp-pointed, the back centre pin is drawn out of its socket, and turned end for end: the end of the pin opposite to the point has a small centre hole for the reception of such pointed work. Iron and steel work may be turned very conveniently by means of a square, but not very accurately; and after the work has been taken out of the lathe, and the square cut off, if it be required to turn the work again in the lathe, it is very difficult to find the true centre.

All works requiring great accuracy, as arbors, screws, axes, spindles, &c. are turned between centre points, thus: a chuck (*fig. 8.*) is screwed to the mandrel by the screw in the part *a*, a steel centre point *b* being formed at the end of it. The point is turned very truly, to be exactly in the centre line of the mandrel. The work is mounted between this point and the point of the back centre; and to communicate the motion of the mandrel to the work, a driver (*fig. 9.*) is screwed fast on that end of the work nearest the chuck. The driver is an iron ring, with a screw *d* tapped through one side of it, to pinch the work so fast as to prevent the driver slipping round upon the work; and on the side opposite to the ring is a projecting tail *f*.

The chuck (*fig. 8.*) has a steel claw *k* fitted through it, and fastened by a screw: the end of the claw is bent at *e* paral-

lel to the direction of the mandrel, so that the end of it will catch the tail *f* of the driver, and turn it round, together with the work on which the driver is fixed.

The item *k* of the claw slides in and out of the socket, through the chuck, in order to remove the claw *e* to a greater or less distance from the centre point *b*, and adapt the chuck to operate upon different sized drivers, for delicate or large work. This is the most accurate method of turning iron work in a mandrel lathe, because the centre points at the ends of the piece are preserved. When one end of the work is finished, the driver may be shifted to the other end. Such work may at any time be mounted again upon its original centre points, in any kind of lathe, to turn wheels, collets, &c. which may be fitted upon it.

The form of the driver is shewn in *fig. 30.* In order to make it fit different sizes, the side of the ring opposite to the screw *d* is made angular, and the point of the screw forces the work into the angular part.

This driver may be fixed on either end of the work, whilst the other end is turning; but when it is necessary to fix the driver on that part of the work which is finished, the end of the screw *d* is apt to pinch and bruise it; it is therefore proper to interpose a piece of iron between the point of the screw and the work. But it is better to use the driver shewn in *fig. 31*: it is composed of two bars of iron, united by two screws passing through one bar and tapped into the other: both bars are somewhat hollowed out in the middle, that they may encompass the work. If this should be found to injure the work, a piece of sheet-lead wrapped round it before the driver is put on will prevent it from damaging the work; and if the screws of the driver are drawn very tight, it will carry the work about with sufficient force to bear turning.

When a piece of iron or steel work is to be turned, the centre points at the ends must be found with great precision before it is turned, because it is difficult to cut away great protuberances in metal. The centres are first found by the compasses, and marks are slightly punched in the ends by a conical-pointed punch. The workman now places the work in the lathe, between the points of the mandrel and that of the back centre, but without fixing any driver on the work; he then screws up the centres, so as to hold the work just tight enough to prevent its falling down. In this state, by turning it round with one hand, while he holds a piece of chalk against it with the other, he ascertains whether it is pitched nearly concentric on the points; and if it varies much at any one point, he turns back the screw to take out the work, and punches new centre points, or alters the old ones, taking care to move them nearer to that side which appeared to project farthest in revolving, and was of course marked by the chalk.

When he has, by repeated trials, found the true centre, he screws up the centre point so hard, that it may effectually mark the end of the work, by forcing the points to the bottom of the marks punched; then taking the work out of the lathe, he drills holes in the ends, at the places which the centre points have marked, and to such a depth, that the points of the lathe will not reach the bottom. When the work is again returned into the lathe, it will run very nearly concentric, and the driver being screwed fast on either end of the work, as is most convenient, the work will be turned round by the clutch projecting from the chuck.

The work is now ready for turning, which is done by different tools, and applied in a very different manner from the chisels and gouges for turning wood. *Figs. 37.* to *40.* are different examples of the manner of turning metals: a tool applied in the manner of *fig. 39.* operates very well upon

upon brass and bell-metal. The cutting edge should be ground nearly to the angle which is there represented, and the upper side should be directed nearly to the centre of the piece; the edge will then scrape away shavings from the metal. The tool has some tendency to retreat backwards from the work, and must be held firmly thereto. The edges of tools, applied as shewn in *fig. 39*, may be formed to any of the shapes shewn in *figs. 23* and *24*, the angle of the cutting edge being in all cases nearly the same.

The graver (*fig. 40*.) is an extremely useful tool, and fit for turning any metal or hard wood: it is a square bar of steel, cut off obliquely, and the greatest obliquity of the cutting plane is in the direction from one angle of the square to the opposite angle. This produces a prominent point on one of the angles, which point is applied to the work in the manner shewn in *fig. 40*, and cuts off continuous shavings instead of scrapings: this is owing to the direction of its edge, which is disposed obliquely to the motion with which the work meets the edge in its rotation. The turner should be provided with gravers of all dimensions.

Fig. 37, is the action of what is called a *heel* tool for turning wrought iron or copper: the edge of this is applied nearly in a tangent to the work, on the same principle as the chisel is applied to cut wood. The heel of the tool is placed upon the rest, and being just opposite to the edge on which the pressure or drift of the work lies, the tool cannot escape from its work, although the pressure upon it is very great, so much so, that it would be impossible to keep the tool to its work, if it were held upon the rest, as in the case of the wood chisel, merely by the lateral friction on the rest. The handle of the heel tool is long, and is held inclined upwards, so that the workman can rest the end of it on his shoulder, whilst he holds it very firmly down on his shoulder and on the rest with both hands. This firm position is very necessary, because the heel tool is liable to draw deep into the work, and take away too large a chip. This tool will cut away thicker chips than any other, being what the workmen term a greedy tool. The requisite height of the rest, to make the edge of the tool a tangent to the proper point, is a matter of importance, and requires the attention of the workman, who can only learn the management of this tool by experience. It is not well adapted for finishing work with accuracy, but is very expeditious in roughing out wrought iron: it generates so much heat in working, that it is necessary to keep it constantly wet; and in large lathes, a constant stream of water is made to fall on the edge at the place where it is cutting. The graver and all other tools work wrought iron and steel to the greatest advantage when wetted.

Fig. 39, is the tool used for turning cast-iron; this substance must be scraped away, and it is plain from the figure, that the cutting edge is presented very nearly in the same manner, with respect to the work, as in *fig. 39*; but from the hardness of cast-iron, it requires a very considerable force to press the edge against the work, and it would be impracticable to hold it up effectually on the plan of *fig. 39*; hence the tool in *fig. 38*, is bent at the end, and is lodged over the edge of the rest, in the manner of a lever; the handle is pressed down at the extremity, and lifts up the edge against the work with very great force. The workman must bear on the handle of this tool with the requisite pressure; and in large work, such as cannon and mill-shafts, he usually seats himself upon the end of the tool, which is made very long in the handle.

Different substances require different velocities of motion to cut with the greatest advantage. Wood can scarcely be made to move too quick; and it is always preferable to take a very thin chip, and move as quick as possible, than to move

slowly, and compensate for the loss of time by cutting deep. Brass and bell-metal may be moved very quick, but not with half the velocity of wood. Wrought iron and copper must be turned more slowly, and the tool must be kept wet. Steel should go rather slower than wrought iron, for it is liable to have hard veins in it, which the workmen call pins: these will be cut through if the work moves slowly, but with a quick motion they will destroy the edge of the tool: this makes some workmen think that the pins are actually formed, or that they become hard during the operation of turning, if too great a velocity is used. Cast-iron must move very slowly, indeed it can scarcely turn too slowly, and the tool applied as at *fig. 38*, will cut a thick chip.

To obtain these different degrees of velocity, the foot-wheel of the lathe *fig. 1*, is made with several grooves of different diameters, and the mandrel pulley *b* has also different sizes. A band can be applied upon any of these grooves at pleasure, and the workman finds by experience what velocity is best for different kinds of work.

The most experienced workmen prefer a centre lathe to a mandrel lathe, when they have to turn accurate iron-work, which will admit of being poised between centres; and it is obvious, that the revolving motion of the centre point at the end of the mandrel is of no use; and if the point should be the least out of the centre line, or if the mandrel has any shake in its collar, the work would not be turned truly. But in a centre lathe, where both points are fixed immovably, or, as the workmen say, with dead centres, this cannot happen; and if the work is screwed up tight between the centres, so that there is no shake, the centre points at the ends of the work must be precisely in the centre line of the work.

The manner of giving motion to a piece of work in the centre lathe is, as we have before described, by a loose pulley fitted on the centre pin, and from this pulley a pin projects in a direction parallel to the centre line, so that it comes exactly in the place of the claw *c* (*fig. 8*), and turns the driver round when the pulley is put in motion by the band, either from a foot-wheel or hand-wheel.

When the mandrel lathe is used for centre work, the centre of the chuck must be turned very exactly, so that it does not vary in the least from the same position when it turns round; and in all cases, the mandrel must be fitted with the most scrupulous accuracy into its collar, so that there will be no shake; for unless this is the case, the lathe will not turn chuck-work with any accuracy.

Messrs. Holtzapfel and Deyerlien make very excellent lathes on the plan represented in *fig. 1*. The bed and the puppets are made of cast-iron, and very correctly fitted, such lathes possess great strength: some of them are fitted up, as in the figure, with a pattern screw at the end *a* of the mandrel, for the convenience of cutting screws on work. For this purpose, the mandrel is fitted in a collar at each end, and the necks are cylindrical, so as to admit of the mandrel moving endways at the same time that it turns round. On the extreme end of the mandrel, beyond the collar *D*, a pattern screw is fixed, which has the distance of its threads corresponding with the screw that is desired to be cut upon the work, which is fixed in the lathe by a chuck: a piece of brass, *n*, is provided, which is cut with threads adapted to the pattern screw, and which can, by turning a screw, be drawn up against the pattern screw, so as to work in its threads; and in this state the mandrel, at the same time that it turns round, will move endways in its collars with a screwing motion; and in consequence, a pointed tool being presented to the work, and held fast on the rest, will cut a spiral groove or screw upon its circumference. This contrivance is more fully

fully explained in the article *ROSE-Engine*. It is the most convenient method of all others for cutting screws, and very accurate, if the pattern screws which are fixed on the mandrel are correctly cut. For all purposes of wood turning, it is undoubtedly the best method, and far preferable to the common one of cutting screws flying, as it is called, that is, by means of the tools 32 and 33, which are applied to the work, and moved along endways at the same time that the work turns round, so that they cut a spiral. (See *ROSE-Engine*.) The rapidity and accuracy with which some workmen cut screws in this way exceed belief; but it is only by long experience that this habit can be acquired, and for those who have not had such experience, some mechanical help is necessary. The objections made by accurate workmen to the flying or screw mandrel are, that as the necks must be cylindrical, it cannot be kept so perfectly fitted in its collars as the common mandrels, which have a point at the extremity, and the neck at the other end is made slightly conical, so that it can always be screwed up to fit in the collar. Messrs. Holtzapfels mandrels are made of hardened steel at the necks, and the collars are also hard; they are accurately fitted, and have no shake when new. From the hardness of the materials, they will wear a long time before they get any looseness.

Mr. Maudslay has the most complete set of tools for all kinds of mechanical works at his manufactory, and is particularly well provided with turning apparatus. All his lathes are made with triangular bars, such as is described in our article *LATHES*, and the mandrels are all formed with conical necks and collars. The bar lathes are very accurate, particularly when the slide-rest is applied to them, as there described. The bed lathe may also have a slide-rest applied, as is shewn under *ROSE-Engine*.

If a piece of metal, after being properly turned, is to be bored hollow within, like a gun-barrel, the back puppet is to be removed from the bed of the lathe, and another substituted in its place, having a hole or collar through it, into which the neck or end of the iron is to be correctly fitted, the other end of the iron being supported and turned round by being fitted into a chuck at the end of the mandrel, or else by means of the centre point at the end of the mandrel, and with a driver, as in *figs. 8. and 9.* The rest is to be set opposite the end of the piece where it comes through the collar, and drills or borers are to be applied, similar to those used by locksmiths in boring keys, beginning with a small one and afterwards using larger ones, until the hole is made as wide and deep as necessary. The borers must be held very firm on the rest, otherwise there is danger of not boring the hole straight. The borer should be withdrawn from time to time, to oil it and clean the hole. As it is difficult to make a hole quite round or concentric with the outside by means of borers alone, it is necessary to have also a turning tool considerably smaller than the hole, one of the sides of which is sharp, very well tempered, and a little hollow in the middle. This instrument being fixed in a long handle, is to be introduced into the hollow, and applied with steadiness to the inner surface of the hole, and it will entirely remove every inequality that may have been there before its application.

The collar puppet is only resorted to, when the piece which is to be bored is of considerable length; for if it is short, it will be held sufficiently fast in the chuck, without the necessity of supporting the extreme end.

A collar puppet is sometimes necessary in turning centre work when the work is long, and so slender, that it bends or springs by the stress of the tools: the collar is then applied to support the work at the part where it is weakest and bends most.

Turning of elliptical or oval Work, such as Picture-frames, Snuff-boxes, &c.—This is performed in the same lathe, and with the same tools, as the circular work; but the lathe is provided with a chuck, which causes the work to traverse in a very curious manner, by a motion given to it in a direction to and from the centre of the mandrel as it revolves; so that a tool held up against the work will cut an elliptical figure instead of a circle. Elliptical work has a very singular appearance when in motion; for after the work has been turned truly elliptical, every part of the circumference, except the exact point where the tool was applied, appears to vibrate, or be excentric in a great degree, but that one point of the circumference runs perfectly true and regular, the same as the whole circumference of a piece of circular work does. The mode of action of this ingenious apparatus is rather difficult to describe, and it is first necessary to understand the principle of its action. This is the same as the trammel or elliptic compasses; see *fig. 29.* An octagonal or square board A A, B B, has two grooves cut in its surface, which intersect each other at right angles; this board is held down upon the surface where the ellipse is to be described, with the centre lines of the cross grooves coincident with the two diameters of the intended ellipsis, and of course their intersection will be its centre. The curve D D is traced beyond the circumference of the board, by means of a pen or pencil, which is fixed at F, to a radical bar or beam F G H; this bar carries two other points or pins, G and H, which are attached to sliders, inserted into the cross grooves of the board, as shewn in the figure: the sliders are fitted in truly, so that each of them will have a motion in its respective grooves: thus the slider of the pin H will move along A A; and the slider of G, along the groove B B. By turning about the beam F G H, the sliders go backwards and forwards in their cross grooves with a simultaneous motion; so that when the beam has gone one-fourth way about, one of the sliders will have moved from the circumference of the board A B, to the common centre of the cross grooves; and when the beam has gone half round, the same slider will have proceeded the whole length of the cross, and arrived at the opposite side of the circumference. The same applies to the other slider, and when one slider is at the centre, the other will always be at the circumference.

The pins F and G H can be fixed at any part of the beam at pleasure, (though this is not so represented in the drawing,) for the purpose of setting the trammel to draw any particular ellipsis: thus, place the beam in the direction of the line A A, then the pin G will be in the centre of the cross grooves; now fix F at such a distance from the centre, as is equal to half the small diameter of the ellipse, and set H so far distant from G, as the difference of the two diameters; consequently, from F to H will be equal to half the longest diameter. Now, in turning the beam round from the direction A A, till it comes to the direction B B, the point G will depart from the centre along B B, and H will approach it along A A, till it gets to the centre. Then will the pencil F be so much farther from the centre, as G is distant from H, and the pin has in its circuit traced one-fourth of an ellipse. The beam being turned quite round, will complete the whole curve.

This apparatus may be applied to turning by some modification. Suppose the two cross grooves made in a round board, as large again as that represented in the figure; then, if the whole apparatus be inverted, and the beam F G held fast in a vice, or otherwise, the board with the cross may be traversed round upon the fixed sliders, in the same manner as the beam could be traversed round upon the fixed board. Suppose a tracing point is held to the back of the board, exactly

exactly opposite to the place where the tracing point *F* is fixed to the beam, and held fast; it is evident that its point will trace the same ellipse on the back of the board, that was described on the surface which the board lay upon in the former instance: or a chisel being held fast in the same spot, will cut the board elliptical when it is turned round; and the chisel being successively applied at different points along the line of the beam, a series of concentric ellipses may be turned in the board, to make mouldings for picture-frames or other ornaments. If the distance of the two fixed pins *G* and *H*, and the chisel *F*, is altered, it will vary the proportion between the two diameters of the ellipses, in the same manner as before described of the trammel.

The oval chuck is constructed in a different manner from this, though it preserves the same movements. It consists of three parts, the chuck, the slider, and the excentric circle. The chuck *cef* (*fig. 27.*) is attached to the mandrel by a screw-socket, cut in a piece *f*, which projects from the centre of it behind; and hence the chuck turns round with the mandrel with a circular motion.

The chuck has a dove-tailed groove, formed in it at the front side, for the reception of a slider *g b*, (*fig. 26.*) which traverses freely in the groove: the groove is formed, as the figure shews, by pieces *i, i*, screwed to the chuck on each side. In the centre of the slider, in front, is a screw *h*; see also the plan, *fig. 25.* The screw *h* projects from the slider, and by means of it, a wooden chuck may be screwed against the slider, and any work can be fixed in the chuck in the usual manner. The work so fixed, at the same time that it turns round by the motion of the chuck, has a sliding motion across the centre, which motion being given according to a certain law, produces an elliptic motion. The sliding motion is given by the excentric circle (*fig. 28.*); this is a ring of brass, attached fast to the puppet of the lathe, close to the collar, in which the neck of the mandrel runs. The mandrel passes through the aperture *l*; the ring has a flat plate, *m*, to strengthen it, and forming two bends at the ends *m, m*, which bends have screws tapped through them, and pointing exactly to each other: these screws are sharp at the points, and are inserted into small holes in each side of the puppet, as is shewn in the plan *fig. 25.* at *C*, the back of the plate *m* of the circle lying flat against the front of the puppet *C*; by this means the circle is fixed fast; the two screws are horizontal, and both point to the centre of the mandrel *b*; therefore, by screwing one screw in, and the other out, the whole circle may be moved sideways horizontally, so as to give it any required degree of excentricity from the centre line of the mandrel, and it will be held stationary wherever it is placed.

Fig. 27. is a back view of the chuck, and shews two grooves made through it in the direction of the length of the slider; these admit the shanks of two pieces of steel *n, n*, to pass through the chuck, and they are firmly attached to the slider *g*, by a screw for each in front of the slider, as shewn in *fig. 26.* The two inside edges of the pieces *n, n*, are exactly parallel to each other, and the distance between them is exactly equal to the diameter of the outside of the ring *28*, which ring is included between them, when the chuck is screwed to the mandrel *b*, and the circle fixed to the puppet *C*, as shewn in *fig. 25.*

Suppose then the circle is set concentric with the mandrel; if the mandrel is turned round, it will cause the chuck *c*, and slider *g*, together with the work attached to the slider by the screw *h*, to revolve. The work will now run in a circle, and turn circular work as usual, because the slider is guided by means of its claws *n, n*, which embrace the circle; and will keep the same position in its groove in the

chuck during all the parts of a revolution, because the circle is concentric with the mandrel.

To set the chuck for an ellipse, place the point of a tool opposite the work, at such a distance from the centre of the work, that it will describe a circle of a diameter equal to the breadth or smallest diameter of the ellipse intended to be turned. This is best done by fixing the tool in the slide-rest. Now turn about the mandrel, till the slider *g* comes horizontal, and set the circle *28* excentric from the mandrel by its screws *m, m*; it will of course move the slider *g* in the groove of the chuck, and also the work will move with it to a greater distance from the centre, because the two steel pieces *n, n*, at the back of the slider include the circle between them. The quantity of excentricity given to the ring, must be equal to the difference between the two diameters of the required ellipse, so that the work shall move, or throw out a sufficient distance, to bring the point of the tool as much beyond the circle first described, as the length of the ellipse exceeds the breadth. The point of the tool will now be at one end of the longest diameter, and here we will commence to trace the curve all round. In turning the mandrel round till the slider comes vertical, it must return in its groove to the place it first occupied, *viz.* the centre; because the excentric circle which guides the slider is not excentric in a vertical direction, though it is in the horizontal. In this motion, the point of the tool has cut or described one quadrant of an ellipse, because it gradually approached the centre a quantity equal to the excentricity of the circle. By continuing to turn the mandrel round farther, the circle will cause the slider to move out the other way from the centre in its groove until it comes again horizontal, when it will be at the greatest throw out, as the turners term excentricity, and the point of the tool will be at the other end of the longest diameter, having described one half the curve: continuing to move forwards till the slider becomes vertical, it will become concentric again, and the tool will be at the breadth of the ellipse, having finished three quarters of the ellipse; and in turning the next or fourth quarter, the slider throws out till it comes horizontal, and brings the work to the position where we first set out, *viz.* at its greatest excentricity; and with the tool at the end of the longest diameter of the ellipse.

The simple trammel (*fig. 29.*) is not easily recognized in this complicated chuck, although it has all the same movements. Thus, let us return to our first idea of a board with two cross grooves in the back of it, turning round on two fixed pins, which enter the sliders in those grooves. Suppose that one of the pins is extended to a large ring, and the groove proportionably widened to receive it, this will have the same effect. Such a groove is formed by the two pieces of steel *n, n*, which have straight edges made truly parallel to each other, and perpendicular to the length of the slider which carries them. The other fixed pin is represented by the mandrel; and the slider being always confined in a right line across it, has the same effect as a pin entering a straight groove.

This ingenious apparatus was invented early in the last century by the celebrated mathematician Abraham Sharp. Before his time, oval-work was always turned in a rose-engine, which had an elliptical pattern.

In turning oval work, the tools must be delicately used, because the circumference moves with an unequal velocity at different parts of its revolution.

Method of ornamenting turned Articles by an Excentric Chuck.—This produces a similar effect to the rose-engine; but as a chuck of this description can be applied to any lathe which has a mandrel and slide-rest, it has been reserved for the present article.

Figs. 18. and 19. are two views of an excentric chuck: a

is a socket, which is screwed to the mandrel; and *bb* the chuck, which is formed in the same piece with the socket *a*; a dove-tailed groove is formed in the front of the chuck, by means of two pieces *d, d*, which are screwed to the chuck, and into this groove a slider, *ee*, is fitted: to this slider a centre pin is fixed very firmly, and upon the centre pin a circle, *f*, is fitted, so as to turn round freely; in the front of the circle a screw, *g*, projects, for the purpose of fixing chucks to the circle. The slider is applied to the chuck, just the same as in the oval chuck, but is not left at liberty to slide in the groove, for a screw, *k*, is applied, which will move the slider gradually in the groove, but always holds it fast where it is placed. By means of this screw, the centre pin of the circle, *f*, can be made either to coincide with the line of the mandrel, or it can be set with any required degree of excentricity from the mandrel, as is shewn in *fig. 19*, by the difference between the line of the screw *g*, and that of the socket *a*.

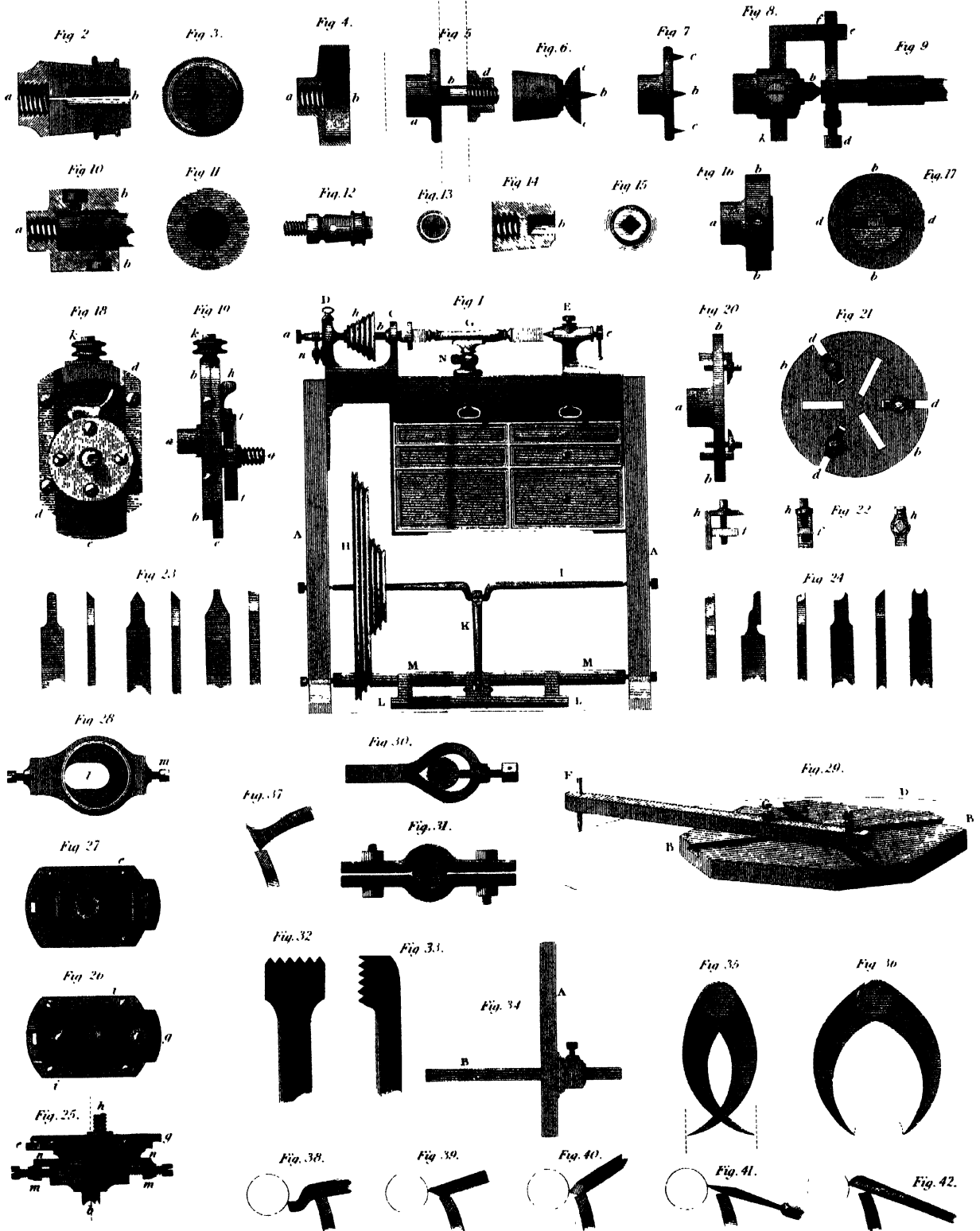
The circle is divided round the edge with notches or teeth, cut at equal distances; and a tooth or catch, *h*, is fitted on the slider by a centre screw, and has a tooth which can be inserted into any of the teeth at pleasure, and will hold the circle fast from turning round upon its own centre pin. In this case, any piece of work, which is fixed to the screw *g*, will turn round with the mandrel, just as though it was fixed immediately thereto. The manner of using this tool is as follows: when the excentric chuck is screwed to the mandrel at *a*, the screw, *k*, is turned, until the screw, *g*, is brought exactly into the line of the mandrel. A wood chuck is now screwed on at *g*, and a piece of work fitted into it; which work is turned to its required figure, just as though the wood chuck was screwed to the mandrel itself, without the interposition of the excentric chuck, which hitherto has been passive. The work being turned, it can be beautifully ornamented on the flat surface, by tracing a number of circles upon it. To do this, turn the screw *k*, until the centre of the circle, *f*, is removed to a given distance from the line of the mandrel; now apply a tool to the end or flat surface of the work, by means of the slide-rest, and turn the mandrel round, until the tool has cut a fine circular line in the surface of the work. Now it is evident that this circle will not be in the centre of the work, but removed from the centre thereof a distance equal to the degree of excentricity given to the slider. Having thus described one circle, stop the lathe, and release the catch *h*; then turn the circle, *f*, round one tooth or notch.

Put the lathe again in motion, and describe another

circle by the point of the tool, held exactly in the same spot as before; but the circle so described will fall on a different part of the work to that circle which was before made, although its centre will be at the same distance from the centre of the piece of work. The lathe is stopped, and the circle, *f*, turned round another tooth: a third circle is then described; and when as many circles are described as the whole number of teeth in the circle *f*, the ornamenting is finished. It will consist of as many circles as there are divisions in the circle *f*, all of an equal size, and their centres arranged at equal distances, around the circumference of a small circle, which is concentric with the work. The whole produces a rosette or engraved figure upon the surface of the work, and the numerous intersections of the excentric circles have a very pleasing effect to the eye. This kind of work is seen on the cases of many watches; and when well executed, is much esteemed.

TURNING Horizontal Hand-Mill, in *Rural Economy*, an useful contrivance of the hand corn-mill kind. It was invented by Mr. Wright, and consists of a sort of tub or box; the frame of the mill-part of which is three feet square, and three and a half in height. The mill-stones are eighteen inches in diameter, and inclosed in the tub or box, supported by two cross-bearers, under which is a lever, having an iron pin or pivot, which runs through the centre of the bed stone into a socket in the bridge of the upper stone or runner, to which is attached the shaft and spindle, running through the eye of the runner and hopper, and supporting the fly-wheel and crank. A piece of wood of a round form, fastened on the shaft, serves as a feeder; and above is a screw to regulate the feed according as the mill is turned. On the side of the tub or box is a thumb-screw, fixed to the lever underneath, which regulates the stones, according as they are turned. The shaft runs through the crown-tree or cross-bar at the top of the frame, on which is the horizontal fly-wheel and crank; to which are attached one or two handles, by means of which the mill is put in motion. Under the stones is a drawer; in which are placed three sieves of different finesses; one for taking away the broad bran, another for the coarse pollard, and the third for stopping the fine pollard, and letting the flour pass into the drawer, which is effected by a sort of iron fork running through a hole in front of the drawer, and fixing on one of the sieves.

Small hand-mills of this nature are extremely convenient and useful in many cases.



Varnish

VARNISH, or *Vernis*, *Vernix*, a thick, viscid, glossy liquor, used by painters, gilders, and various other artificers, to give a gloss and lustre to their works, as also to defend them from the weather, dust, &c.

There are divers kinds of varnishes; some of the principal of which are as follow:

VARNISH, Amber, is prepared in the following manner: Put four ounces of amber into a crucible, and melt it with a small degree of heat, and pour it out upon an iron plate; when cold, reduce it to powder, and add to it two ounces of drying oil, that is, linseed oil thickened by boiling it up with litharge, and one pint of oil of turpentine, and dissolve the whole together into a liquid varnish.

This simple amber varnish is of great use for many purposes, and is said to be the basis of the fine varnishes which we see on coaches, and may be prepared without drying oil, by boiling the powder of amber in linseed oil, or in a mixture of linseed oil and oil of turpentine. Drying oil is commonly used by the workmen; but Dr. Lewis thinks it more eligible to take the oil unprepared, that the boiling requisite for giving it the drying quality may be employed at the same time in making it act upon the amber. It has generally been thought, that amber will not at all dissolve in oils, till it has suffered a degree of decomposition by fire. But Hoffman relates an experiment, in his *Observationes Physico-Chemicæ*, which discovers the solubility of this concrete in its natural state. Powdered amber, with twice its quantity of oil olive, was put into a wide-mouthed glass; and a digester, or strong copper vessel, being filled about one-third with water, the glass was placed in it, the cover of the digester screwed down tight, and a moderate fire continued an hour or more: when cold, the amber was found dissolved into a gelatinous, transparent mass. In Dr. Stockar's *Specimen Inaugurale de Succino*, printed at Leyden in 1760, we have an account of other experiments made by himself, in conjunction with M. Ziegler of Winterthur; from which we learn, that

by continuing a simmering heat twelve hours, and confining the vapour as much as stone-ware vessels would bear without bursting, (the danger of which was avoided by making a small notch in the cork-stoppers,) powdered amber dissolved perfectly in expressed oils, in turpentine, and in balsam of copaiba: a strong copper vessel, with a cover screwed on it, seems most digible; and for the greater security, a valve may be made in the cover, kept down by a spring, that shall give way before the confined vapour is of sufficient force to endanger bursting the vessel. Moreover, by digestion for a week in close-stopped glass vessels, in which the compressure could not be very great, solutions equally perfect were obtained. The solution in rape-seed oil, and in oil of almonds, was of a fine yellowish colour; in linseed oil, gold-coloured; in oil of poppy-seeds, yellowish-red; in oil olive, of a beautiful red; in oil of nuts, deeper coloured; and in oil of bays, of a purple-red. The solutions made with turpentine and with balsam of copaiba, were of a deep red colour, and on cooling, hardened into a brittle mass of the same colour. All the solutions mingled perfectly well with spirit of turpentine. Those made with the oils of linseed, bays, poppy-seeds, and nuts, and with balsam of copaiba and turpentine, being diluted with four times their quantity of spirit of turpentine, formed hard, tenacious, glossy varnishes, which dried sufficiently quick, and appeared greatly preferable to those made in the common manner from melted amber.

An amber varnish may also be made by boiling down some colophony, or turpentine, till it becomes black and friable, and melting this in a glazed earthen vessel, sprinkling in, by degrees, thrice as much amber in fine powder, with the addition of a little spirit or oil of turpentine now and then. When the amber is melted, sprinkle in the same quantity of farcocola, continuing to mix them, and to add more spirit of turpentine, till the whole becomes fluid; then strain out the clear

clear through a coarse hair bag, pressing it gently between hot boards. This varnish, mixed with ivory-black in fine powder, is applied, in a hot room, on the dried paper paste of which the *papier mâché* is made; which is then set in a gently heated oven, next day in a hotter oven, and the third day in a very hot one, and let stand each time till the oven is grown cold. The paste thus varnished is hard, durable, glossy, and bears liquors hot or cold. Lewis's Com. Phil. Techn. p. 367.

An amber varnish may be otherwise made by melting eight ounces of Chio turpentine, and when fluid, pouring into it, by degrees, a pound of fine powdered amber, and stirring it; and when it is properly mixed, setting it on a fire for half an hour, taking it off, and stirring it well, and adding to it two ounces of the white colophony. It is again to be put on a brisk fire, and covered close; when the mass is perfectly fluid, and taken off to cool, a pound of linseed or poppy oil, made drying, is to be poured in boiling hot, and stirred till it be incorporated with the mass; and then a quart of hot turpentine is to be added, and the whole well stirred. Let it then cool, and strain it off for use; when, if it has been properly made, it will be quite clear. See *GILDING on Enamel and Glass*.

VARNISH, Black, for japanning on wood or leather, is prepared by mixing lamp-black or ivory-black with a proper quantity of a strong solution of gum lac in spirit of wine. (See *JAPANING*.) The lamp-black is commonly preferred to the ivory-black, on account of its uniting better with the fluid, and working smoother. The thicker part of the varnish, which settles at the bottom, is used with the lamp-black for the first coatings, and the mixture applied at different times, in a hot room, one layer after another, is dry, till a full body of colour is obtained; after which, the piece is washed over in the same manner several times, with the finer part of the varnish, just tinged with the black, so as to make a coating of sufficient thickness to bear polishing with tripoli. Iron snuff-boxes, mourning buckles, &c. are coloured black, by making them considerably hot, and applying on them in this state a thick mixture of lamp-black, with a certain varnish called gold-size, consisting of drying oil, turpentine, and the pigment called Naples yellow; but the yellow might be omitted, and the varnish formed at once by mixing lamp-black with a proper quantity of turpentine and drying oil. The workmen, as Dr. Lewis says, frequently employ, as varnish for metals, a mixture of lamp-black, with the scummings, &c. of different oil paints; the mixture is applied with a pencil, and the piece afterwards baked in an oven with a heat somewhat greater than is used for the *papier mâché*. Naples yellow, a superfluous ingredient in the black varnish, is the basis of the dark-brown which we see on some iron snuff-boxes; this pigment changing to a brown in baking with the varnish. Lewis. See *LACQUER*.

The excellent black varnish of China and Japan, which has been hitherto but imperfectly imitated in Europe, and which was formerly thought to be an artificial composition of refinous bodies coloured with black pigments, has been discovered by the later travellers into those countries, to be a native juice, exuding from incisions made in the trunks of certain trees. Mr. Miller, in consequence of a letter from the abbé Mazeas to Dr. Hales, containing a communication of the discovery of a plant by the abbé de Sauvages, which he calls *toxicodendron Carolinianum foliis pinnatis, floribus minimis herbaceis*, and the black juice of which adheres, without the least acrimony, to cloth with more force than any other known preparation, takes occasion to shew, that this American toxicodendron is the same species of plant from which

the inhabitants of Japan procure the varnish with which they stain all their utensils; adding, that the Calicuts are also painted with the juice of this shrub. This American toxicodendron (see *POISON-TREE*) is the same plant, as he affirms, which is mentioned by Kämpfer, in his *Amœnitates Exoticæ*, by the title of *arbor vernacifera legitima, folio pinnato juglandis, fructu racemoso cicoris facie*; i. e. the true varnish-tree, with a walnut-tree leaf, and a branching fruit like cicers. It is called by the inhabitants of Japan *sitz*, or *lisitz-dzju*, and also *urus*, or *urus-noki*. Kämpfer has also described the wild or spurious varnish-tree, called *fusi-no-ki* by the natives, which he says agrees with the other in every part, except that the lobes of the leaves are narrower; but Mr. Miller is of opinion that this is a distinct species, if not a different genus, from the true sort; and says, that the varnish yielded by it is of little esteem. The account which the Jesuits at China have given of the manner in which the varnish is procured, is as follows: they first slit the back of the branches of the shrub, in different places, with a knife; and thus there flows out a white clammy juice, which is received into wooden vessels; and when these become dry, they tap the stems of the shrubs near the roots, so that all the juice is drawn out of them. The shrubs are then cut down to the ground, and from their roots new stems arise, which in three years will be fit for tapping. The juice turns black when exposed to the air; it heats without turning sour; but being of a poisonous nature, it is dangerous to handle it. This native varnish wants hardly any preparation; but if any dirt should happen to mix with it, it is cleansed by being strained through coarse gauze, put into wooden vessels, and covered with an oil called *toi*, and a skin, in order to prevent its evaporating. In this state it is carried over to China and Japan for sale. The shrub is chiefly cultivated in the provinces of Tsi-koeko and Figo; and the best varnish, according to Kämpfer's account, is produced about the city Jassio; but there is an ordinary sort of varnish, called *nam-rak*, brought from Siam, which is collected in the province of Corfania, and in the kingdom of Cambodia, from the tree *anacardus*, called by the inhabitants *tong*, or *tue-rak*, the fruit of which is called in our shops *anacardium*. To collect this liquor, they bore a hole in the trunk, and insert a tube. By this method they procure as much of it as is sufficient, not only to varnish all the utensils of China, Tonquin, and Japan, but it is even exported in close wooden vessels to Batavia, and other parts of India. This varnish, says Kämpfer, is not only sold quite pure, but likewise coloured, with Chinese native annabar, and a kind of red earth, which the Dutch formerly, but now the Chinese bring them, and also with the materials of which they make their common Japan ink. Mr. Ellis has controverted the opinion of Mr. Miller, and endeavoured to shew that the American toxicodendron is not the same with Kämpfer's *arbor vernicifera legitima*; alleging, that Kämpfer's description of the true varnish-tree does not agree with this toxicodendron; and he inclines to the opinion, that the Carolina pinnated toxicodendron, or poison-ash, is the same with the *fusi-no-ki*, or spurious varnish-tree of Kämpfer. Mr. Ellis also thinks it is not improbable, that the varnish mentioned by Kämpfer, as obtained from the oriental *anacardium*, is the same with that mentioned by father d'Incarville, in the Phil. Transf. vol. xlviii. p. 254, called *ta-ng-yeou*; which is so universally used in China for preserving and ornamenting their furniture. See this controversy between Mr. Miller and Mr. Ellis at large, in Phil. Transf. vol. xlix. part i. p. 157—166. part ii. p. 806—876. vol. i. p. 430—456. See *POISON-TREE*, *LINEN*, and *JAPANING*.

VARNISH, Brown, for Metals. See *Black VARNISH*, *supra*.

VARNISH,

VARNISH, Copal Oil, called in France *vernis martin*, is made by pouring into a well-glazed strong earthen pot, in shape resembling a chocolate pot, and in size large enough to hold about a gallon, and made warm, four ounces of Chio or Cyprus turpentine, and when this is dissolved, eight ounces of finely powdered amber; mingling them well, and setting them on the fire for a quarter of an hour; take off the pot, and pour gently into it a pound of copal, finely bruised, but not powdered; stir the mass, and add four ounces of Chio turpentine, and a gill of warm turpentine oil; then set it on a brisk fire for about half an hour, and taking it off, stir the contents well, and add two ounces of the finest and whitest colophony. Let the pot be put on a very brisk fire, and remain till the whole is dissolved, and become as fluid as water; let it be removed from the fire, and remain for a few minutes, and then gradually pour in twenty-four ounces of poppy, nut, or linseed-oil, made drying, and boiling hot, and stir the mass with a deal stick. When the gums and oil are thoroughly incorporated, set them over the fire for a few minutes, still stirring them about, and let them boil once up; and having taken off the pot, pour into it a quart of hot turpentine; stir them together, and give them one boil up; take off the pot, and pour into it a pint more of hot turpentine, still stirring it well. If the gums are thoroughly melted, and well incorporated, the varnish is made; which, being cool, is strained through a close cloth into another vessel, and, if it be too thick, thinned with oil of turpentine, till it becomes of the consistence of linseed-oil; strain it a second time, bottle it for use, and let it stand a month, at least, before it is used. This varnish is used for coaches, cabinets, &c.; and the piece, whatever it be, after having been varnished smoothly, and dried in the intervals half a dozen times, and suffered thoroughly to dry, must be rubbed with a wet coarse rag, dipped in pumice-stone, powdered and sifted, till the streaks of the brush and all blemishes are removed. When it is perfectly smoothed, washed, and dried, the coats of varnish are to be repeated, for ten or twelve times, till there be a sufficient body. After having again used the powdered pumice-stone, and washed it off as before, let it be rubbed with fine emery, till the surface becomes even and smooth as glass; then with powder of fine rotten stone, till by passing the palm of the hand two or three times over the same place, you discover a gloss equal to that of glass: having dried it clean, dip a rag, or piece of flannel, in sweet oil, and rub the surface a few times over, and clear it off with fine dry powder, flour, or the hand; and a piece of fine flannel, dipped in flour, and rubbed over it, when cleared of the oil, will give it an excellent lustre. Between every coat of varnish it will be advisable, if the subject admits of it, to set it in a warm oven; or to heat the varnished pieces by stoves. See **COPAL**.

VARNISH, Gold-coloured. See **LACQUER**.

The composition of a gold-coloured varnish, used by the English artists for brass and silver, was communicated to some of the French academicians in 1720, by Mr. Scalet, and in 1738 by Mr. Graham, and published in the volume of the French Memoirs for 1761. It is as follows: Take two ounces of gum lac, two ounces of yellow amber, forty grains of dragon's blood in tears, half a drachm of saffron, and forty ounces of good spirit of wine: infuse and digest in the usual manner, and then strain through a linen cloth. The piece to be varnished must be heated before the liquid is applied: it receives from the varnish a gold colour, and may be cleaned, when sullied, with warm water.

VARNISH for preserving polished Iron from Rust. See **IRON**.

Many methods have been used for preserving iron utensils from rust, as animal fats, oils, boiled oil mixed with melted lead, &c. Homberg's salve for this purpose consists of two pounds of hog's-lard, an ounce of camphor, and as much black lead as will render the mixture of an iron-colour; when this is used, the iron must be previously heated. M. Reaumur has discovered a better composition for this purpose: it is oil, inspissated by being exposed to the air in flat shallow vessels, so as just to cover the bottom, mixed with a solution of copal in spirit of wine: this forms an elegant hard varnish, which, rubbed on polished iron, made a little hotter than the hand can bear, will cover it with a solid, thin, transparent coat, without any injury to its colour or appearance. See **RUST**.

VARNISH, Lacca, is made of gum lacca and spirit of wine, frequently shaken till the gum be dissolved, then strained, and the clear liquor decanted off.

The lacca ought to be of the kind called seed lacca. (See **LAC**.) Three ounces of this, well purified by repeated ablution of water, dried and powdered grossly, should be put into a bottle with a pint of rectified spirit of wine, so as to fill about two-thirds of it, and the bottle placed in a gentle heat; proceeding as above: though for varnishing ordinary woods, shell lacca is often used. For this purpose, five ounces of the best shell lacca should be grossly powdered, and put into a bottle, holding about three pints or two quarts, with one quart of rectified spirit of wine; and placed in a gentle heat: the mixture must be filtered through a flannel bag. To this varnish, the colours used in varnish painting may be added, and properly diluted with rectified spirit, and kept in phials, or tin vessels closely stopped for use. But this will not stand against the weather.

For various preparations of this kind, see **JAPANNING** and **LACQUER**.

VARNISH, Mastich, is made by putting five ounces of powdered mastich into a proper bottle, with a pound of spirit of turpentine, and setting them to boil in balneo Mariæ, till the mastich be dissolved, and straining the solution through flannel. This varnish may be converted into a proper varnish for painting, by grinding one ounce of gum anime on a stone with water, till it becomes an impalpable powder; then drying it, and grinding it again with half an ounce of turpentine, and afterwards with the proper colours, and moistening it with the mastich varnish, till the mixture be of a due consistence for working with the pencil. It must then be kept in phials or tin vessels, and diluted, as there may be occasion, with spirit of turpentine.

VARNISH for preserving Paintings. See **PICTURE**.

For this purpose some have recommended the following composition: viz. half a pound of gum sandarac; an ounce and a half of Venice turpentine; three-quarters of an ounce of each of the gums anime and copal; half an ounce of mastich; benzoin, gum elemi, and white resin, each two drachms, and one pound of rectified spirit. The benzoin and gum anime powdered, are put with the Venice turpentine into a phial, with eight ounces of the spirit of wine; the copal and resin powdered are also put in a phial with six ounces, and the powdered gum elemi, with two ounces of spirit of wine. The several phials are frequently shaken, till the gum, &c. are dissolved; then the solutions are strained through a fine linen in one bottle, and when the mixture has stood some days, it is decanted off clear, and kept in a separate bottle for use. Some have substituted the sarcocolla for the copal. Another composition is formed, by dissolving mastich and sandarac, grossly powdered,

dered, of each six ounces, and Venice turpentine half an ounce, in a quart of highly rectified spirit of wine, and straining off the solution. If it be required harder, an equal weight of the gums anime and copal may be added, and the quantity of spirit of wine doubled. In the use of this varnish, the painting should be thoroughly dry, and it should be spread very gently with a pencil. The varnish should be laid on in a very warm place, or the picture itself warmed to a moderate degree, in order to prevent the *chilling* of the varnish; in which case another coat should be added. And, indeed, two or three coats are necessary to preserve the painting, and to bring out a due effect of its colours, if they are in that state called *sunk in*, occasioned by the attraction of the cloth on the oils mixed with them. An oil of turpentine varnish may be added by grossly powdering mastich and sandarac, of each four ounces; two ounces of white resin; and sarcocolla, anime, copal, and olibanum, of each one ounce; and putting them into a phial with two pounds of oil of turpentine, stopping the phial gently, and placing it in any heat, so that the mass may not boil, and straining off the solution for use. Or, a varnish more simple, and equally good, may be made by powdering two ounces of sandarac, mastich and olibanum, of each an ounce and a half; or three ounces of mastich, and Venice turpentine half an ounce; and dissolving them in half a pound of oil of turpentine, and proceeding as before. Handmaid to the Arts, vol. ii. p. 227, &c.

VARNISH for Paper-hangings. See PAPER-Hangings.

VARNISH for Printers' Ink. See PRINTING-Ink.

VARNISH, *White*, is usually made of gum sandarac and gum mastich, dissolved in spirits, left to settle two days, then strained through a linen cloth, and, after standing some time, the clear poured off, and bottled for use.

The more curious artists dissolve the two gums separately; and having made a separate varnish of each, mix them occasionally, as their work requires a stiffer or a softer varnish.

But for the *best* white varnish more gums are required; viz. Venice turpentine, gum copal, elemi, benzoin, anime,

and white resin.

Besides these, there are *hard* and *soft* varnishes, or grounds, used by the etchers and engravers. See ETCHING.

VARNISH is also used for a kind of glossy coat, with which potter's-ware, Delf-ware, China-ware, &c. are covered, to give them a smoothness and lustre. Some preparation of lead is the varnish ordinarily used for the first; and earths for the second. See GLAZING and POTTERY.

The true varnish used by the Chinese and Japanese, to give that inimitable lustre to their porcelain, is one of the grand secrets in that manufacture; and is one of the great things wanting, to make Delf and French ware vie with the Chinese. Several have described the preparation of it, particularly Kircher: but none ever succeeded in the trial. See PORCELAIN and VARNISH, *supra*.

VARNISH is also a term applied to the colours which antique medals acquire in the earth.

The value of a medal is heightened by a beauty, which nature alone was able to give, and art has never yet attained to counterfeit: we mean the colour or varnish with which certain soils tinge the medal; some with a blue, almost as beautiful as that of a turcois; others with an inimitable vermilion colour; and others with a glossy shining brown, infinitely beyond any of our figures in bronze.

The most usual varnish, however, is a fine green, which hangs to the most delicate strokes without effacing them; much more accurately than the finest enamel does on metals. Brass alone is susceptible of it; for as to silver, the green rust that gathers on it, always spoils it; and it must be scoured off with vinegar; or lemon juice.

There is also a *false*, or *modern* varnish; which the falsifiers of medals give to their counterfeits, to give them the air of antiquity: it is discovered by its being softer than the natural varnish, which is as hard as the metal itself.

Some lay their spurious medals under ground, where they contract the degree of varnish, that they impose on the left: knowing: others use sal ammoniac, mixed with vinegar; others the acid spirit of nitre, &c.

Veins

VEINS, *Metallic and Mineral*, in *Geology*, are fissures intersecting rocks or strata, filled more or less completely with mineral or metallic matter, different from the substance of the rock. When veins are seen on the surface intersecting or traversing a mountain, they have been supposed to resemble the veins of animals; but the resemblance is only superficial, for veins are not tubular, except in a few instances; but their thickness is small, compared with their length and depth.

Metallic veins are the principal repositories of most of the metals, except iron and manganese, which occur more frequently and abundantly in beds than in veins. The thickness of metallic veins varies from a few inches to several feet or yards: the same vein varies also in thickness in different parts of its course, sometimes contracting to a narrow string of ore, and then expanding again to the width of several yards. The depth to which they descend is unknown, for we believe no instance has occurred of a considerable vein *being worked out in depth*, though it may sink too deep to render the operation of the miner profitable; or it may branch off in a number of strings, which are too much intermixed with the rock to be worked to advantage. In cases where the metallic ores have disappeared at considerable depths, the veins are still continued, though they are filled exclusively with the mineral matter or vein-stone which accompanied the ore in the upper part of the rock. Some veins appear to grow wider, and others to contract as they descend. The direction of veins downwards inclines more or less from the perpendicular; but they sometimes run for a certain distance parallel with the dip of the beds or strata in a mountain, and then strike down through the lower beds.

The length of metallic veins has rarely, if ever, been accurately determined; they have frequently been traced several miles, but their further progress has been concealed by the intervention of valleys, rivers, or accumulations of sand and alluvial deposits. Some of the metallic veins in South America have been traced to the distance of eighty miles. Large veins generally take a nearly direct line through a country, except where they are turned aside by cross veins, or what are called in Cornwall *cross courses*: it is also remarkable, that the metalliferous veins in England generally run nearly east and west, and the cross courses north and south. To what cause this is owing we are perfectly ignorant. Large metalliferous veins frequently send off smaller veins, or strings of ore, from their sides, which penetrate the rock to a considerable distance on each side of the large vein. Veins are seldom entirely filled with ore, but sometimes it extends in a compact mass from one side to the other. More frequently, the ore is intermixed with mineral matter called vein-stone, *matrix* or *gangue*: this, according to the rock which it intersects, will be either calcareous spar, fluor spar, barytes or quartz. The vein-stone and the ore are frequently arranged over each other, lining the sides of the vein with alternate layers of metallic and mineral matter,

and filling up the whole vein. In the mines of Cornwall, the ores of copper and tin commonly occur in detached masses, which are called *bunches* of ore; and the other parts of the vein, being unproductive, are called *deads*.

The vein is generally separated from the rock which it intersects by a thin layer of mineral matter distinct from the vein, and from the rock itself, and also by a thin lining of clay. Sometimes there are large cavities in veins called *druses*, which are generally lined with crystals. In other instances the vein divides, inclosing a piece of rock, which is called the *rider*; but it is observed, that the inclosed mass, or rider, differs in its quality from that of the rock through which the vein passes.

The superficial part of a vein generally contains the ore in a decomposing state; and it frequently happens that the ores in the upper and lower part of the vein are different: thus in Cornwall, blende, or the sulphuret of zinc, often occupies the uppermost part of the vein, to which succeeds tin-stone, and at a greater depth, copper pyrites. See ZINC, TIN-STONE, and COPPER.

When Mr. Pryce wrote his "*Mineralogia Cornubiensis*," the mines of Cornwall had not been worked to a great depth, for he says the richest state of a mine for copper was from eighty to one hundred yards deep, and for tin, from forty to one hundred and twenty yards. This account by no means corresponds with the present state of the Cornish mines. The Dolcooth copper-mine, near Redruth, is worked to the depth of four hundred and fifty-six yards, and is very productive at that depth.

Veins generally decline from the perpendicular, and descend into the earth obliquely. The sides, or, as they are called, the walls or cheeks of the vein, are differently denominated, the upper side being called the *hanging-side*, the *up-cheek*, or *hanger*; and the under side, the *hading-side*, the *down-cheek*, or the *ledger*. The veins we have been describing are called *rake* veins in some parts of England, and in Cornwall, they are denominated *lodes*; which see. These metalliferous veins have commonly the same direction, or nearly so, in the same district, and the veins which cross them are generally unproductive, or contain metallic ores of a different kind. They are called *cross courses*, or north and south veins.

Metalliferous rake-veins intersect most of the mountains called primary, such as granite, gneiss, and mica-slate. (See GRANITE, &c.) But they are more abundant in slate-rocks than in rocks of granite or porphyry. (See GRANITE, SLATE, and PORPHYRY.) They also intersect the rocks of transition and mountain lime-stone, which rest upon slate, or alternate with it; but they rarely rise into the secondary strata which contains coal. This fact seems to prove that veins were formed prior to the deposition of the upper secondary strata. When a metallic vein in its descent passes through different kinds of rock, it is frequently observed that the products of the vein vary in each bed; and when it

passes through regularly stratified beds of the same rock, there are particular strata in which the veins are always found most productive, and these in the north of England are called *bearing measures*. If the nature of the rock seems to have produced a change in the quality of the ore, it is no less remarkable that the rock itself is also frequently changed or decomposed in the immediate vicinity of a vein. This change is more apparent in some rocks than in others, particularly in granite, sienite, gneiss, mica-slate, argillaceous schistus or slate, and porphyry. In such instances, according to Werner, it is only one of the component parts of the rock that is decomposed, either the felspar, the hornblende, or the mica, but never the quartz. This change sometimes extends to a considerable distance on each side of the vein, even to a fathom or more; it extends farther in some places than in others, and is most general in those parts where the vein contains sulphur. Sometimes this change in the rock may be perceived so far, that it serves as a guide to the miner; and in following a sterile vein, when he comes to a place where the rock is decomposed, he concludes that the metallic ore will soon be found. In Cornwall, the felspar is frequently changed in the vicinity of a vein, and tin-stone is sometimes disseminated through the rock to some distance on each side of it.

The cross courses or veins which intersect the metalliferous veins, frequently occasion a considerable derangement in the position of metalliferous veins, and, what is still more remarkable, occasion a change in the quantity or quality of their contents. When a vein is cut through by another, either in its line of bearing along a country, or crosses it by declining in a different direction, the vein which is cut through is supposed to be of more ancient formation than the vein which crosses and cuts through it; but it may be doubted, from various circumstances, whether many of these veins were not formed at the same time with the rock itself, or were fissures passing through the rock in different directions, into which the various metallic substances were secreted, during its consolidation. To form a more distinct idea of the structure of a vein and its intersection by cross courses, we refer to *Plate IV. Geology. Fig. 4.* *a a* represent a rake-vein descending obliquely; *b b*, the rock; *c c*, the walls or cheeks of the vein; *d*, an interposing piece of rock, called the rider; *e e e*, the division of the vein into numerous small veins or strings of ore. If the space at *d*, which is supposed to be filled with rock, were empty, or filled with water, it would constitute what is called a druse; and it is in these cavities or druses that all the most beautiful and regular crystallizations of the mine occur. *Fig. 5.* represents the section of a rock containing a metallic vein cut through, and displaced by cross courses or veins of another metal; *a a a* is a vein which appears to have been once continuous, and contains tin; *b, b, b*, represent different veins of copper, which cut through the former, and have upheaved the lower part, and brought them nearer the surface. In *Plate II. Geology, fig. 10.* represents the ground plan or horizontal section of a plot of ground traversed by a vein and a cross course; E.W. represent the east and west sides of the ground. It is in this direction the vein *a a* passes, but it is cut through by the cross vein *b b*, which has carried the western side of the vein and the ground along with it considerably to the north of its original position. Such a fracture and removal of the vein can only be conceived to have taken place by a lateral or horizontal motion of a portion of the ground. Such a motion has been frequently observed during violent earthquakes. For though the ground is heaved upwards, the greater resistance which certain parts offer to this motion must occasion a lateral pressure on other parts of the

earth's surface, and to such a pressure we must also refer the remarkable contortions of the coal strata near Valenciennes. See *Plate II. fig. 9.*

Metallic veins frequently occasion a displacement of the strata when they pass through regularly stratified rocks; and it is observed, that when this displacement is considerable, so as to bring a bed of lime-stone on the same level with a bed of sand-stone or shale, the vein is never so productive as when the opposite sides or walls of the vein are in the same kind of rock. See *Plate II. Geology, fig. 8.* where the different strata *a, b, c, d, e, f, g*, represent different strata on each side of a vein or fault. If *d, d*, are supposed to represent parts of a bed of lime-stone broken by the vein, and *g g* a bed of sand-stone below the lime-stone, but brought on the same level with it by the upheaving of the strata,—in that part of the vein where the lime-stone, *d*, and the sand-stone, *g*, form the walls opposite to each other, the vein will be unproductive, though in other parts of the district, when the vein passes through the same bed of lime-stone, on each side of it, at the same level, it will be remarkably productive. These facts may be commonly observed in the mining districts of the western parts of Northumberland and Durham, where the strata consist of different beds of mountain lime-stone, sand-stone, and shale. See STRATA, under which article the succession of the different beds is enumerated.

As cross veins generally displace and injure the quality of veins, on the contrary, when east and west veins in a district meet, by a slight variation in their direction or dip, the part where they join is frequently very rich in ore; and where a number of metallic veins cross each other at the same place, they frequently produce a large irregular conical mass of ore of vast extent, from which the different veins diverge, like radii from a common centre. The main shaft of such a vein, which Mr. Williams, in his Mineral Kingdom, calls an *accumulated vein*, “resembles,” he says, “the inside of a glass-house; and the vast capacity of this vein is frequently stored with a rich body of metallic ore, often imbedded in soft mineral soils; but the veins and branches which join and diverge resemble rake-veins, or perpendicular mineral fissures. When the ore is worked out of an accumulated vein, it exhibits a frightful gulf, sometimes fifty or sixty feet wide below, and is often worked down to a great depth from the surface.” A number of these accumulated veins have been worked at Pike-Law, in the county of Durham. Cross courses sometimes contain ore to a small distance from their junction with metallic veins, and in other situations they become so rich as to be worked with advantage. The Botallack mine, on the sea-coast near St. Just, in Cornwall, offers a striking illustration of this, though we believe its structure has not been generally known or understood. The vein which is worked is a north and south vein, varying in width from nine to twelve feet, and extending under the sea. The vein-stone is quartz, with a small quantity of fluor spar. It is found to contain ore of copper and tin only in those parts where the east and west veins enter it, and for thirty or forty fathoms on each side of the junction. This mine produces the richest ore of copper in Cornwall, the grey sulphuret yielding twenty *per cent.* of this metal. It is deserving notice, that the metalliferous veins which enter this lode on the east side and render it productive, have never been found on the west side, so that they appear to terminate in it. The rock near the great north and south vein is a soft killas or slate, but beyond this it is a very indurated flinty slate. This vein may properly be considered as a cross course, rendered rich in ore in various parts by a number of small veins which fall into it, like brooks into a large river

where they are lost. The situation of this mine is truly remarkable, at the foot of a precipitous cliff that overhangs the Atlantic ocean. If ever a spot seemed to bid defiance to the efforts of the miner, it was this. At the very commencement of his labours, he was required to lower an immense steam-engine down a precipice of more than two hundred feet, with a view of extending his operations under the bed of the sea, where the workings are at present continued for seventy fathoms in length and sixty-five fathoms in depth. In these caverns of darkness, many human beings for a small pittance, and that even of an uncertain amount, are constantly digging for ore, regardless of the horrors which surround them, and of the roar of the Atlantic ocean, whose boisterous waves are incessantly rolling over their heads. In some places the sea actually penetrates through; and it is worthy of observation, that the water is deprived of a great portion of its salts; but whether this arises from filtration, or whether some portion of the fresh water from the land percolated through subterranean fissures in the rocks, we could not ascertain when we visited this singular mine. If the filtration be more abundant after heavy rains, it would prove the intermixture of rain-water. The thin croses courses filled with clay called *flucan*, heave the east and west veins, and also hold up the water. The vein which is rich in ore on one side of the *flucan*, will be poor on the other side. This fact, which we believe has not been sufficiently noticed, is well deserving attention, and would indicate that the presence of water affected the contents of veins.

Some veins contain little diversity in the nature of their contents, being filled principally with one kind of ore or vein-stone. Other veins contain a great variety of minerals, without any apparent regularity of arrangement: there are also numerous veins which have a regular structure, the different minerals being arranged in parallel layers, coating each other: the same succession of different minerals occur on each side and meet in the middle, filling up the vein, or sometimes leaving an empty space between. Thus calcareous spar, fluor spar, barytic spar, lead-ore, blende, and grey copper-ore, form different layers over each other in the same succession on each side of the vein. In the Botallack mine, before described, copper-ore is frequently found lining each side of the vein, and this is covered by tin; but in other parts of the mine the tin covers the walls, and is succeeded by copper.

Irregular Veins.—Besides rake-veins, which may be considered as regular, there are other veins which present a great variety of structure, and are called *bellies*, *pipes*, &c. according to their form. If a rake-vein be regarded as a tubular mass of mineral matter intersecting mountains; if this vein become irregular, and have its sides closed, or, as the miner calls, *twitched in*, it forms what they denominate a pipe-vein, or mass of ore and vein-stone sometimes of a tubular shape, descending to a considerable distance like a pipe. In other instances, the sides are closed in both above and below, as well as on the sides, inclosing what the miners call a *belly*, or mass of ore of considerable magnitude. Sometimes a small rib of ore is continued through that part of the rock where the sides of the vein are twitched in, until the vein expands again and produces another mass of ore. In some instances there is no ore between, a rib of vein-stone or rider of clay being carried through the narrow part or *twitch* of the vein, but many of these twitches contain neither ore, clay, nor rider. In such cases, it becomes exceedingly difficult to follow the vein through the rock, to where it opens out again.

The veins in general do not close suddenly, but the sides gradually approach each other, and the ore terminates in the

form of a wedge at the *twitch*.

These contractions or twitches are of various lengths, and no miner can tell, when the vein is so squeezed in, how many fathoms he must pass through before it opens again, unless the same twitch has before been cut through above or below the part where he is working. The intervening space between two masses of ore is called a *bar*, and sometimes extends ten, twenty, or even a hundred fathoms or more; and when it is cut through, the ore makes its appearance, and begins gradually to widen and form another mass or belly. When one of these bellies of ore proves pure and solid, it generally happens that all the contiguous bellies prove so in the same vein. According to Mr. Forster, instances have been known of eight hundred *hings* of ore being raised by six miners from one of these bellies in the space of nine weeks.

When the matrix in these large bellies of ore is soft, the ore is generally found in a globular form, more or less irregularly imbedded in the soft materials, and these globular masses of ore are of various dimensions. It is no uncommon thing to find the soft openings in this kind of vein swell to an enormous width, so as to make it difficult to find the real sides of the vein. Working these veins is the most difficult part of mining, as there is no proceeding a foot without advancing timbers as far as they go, in the form of a passage in a house, composed of two side-posts, a lintel and a sole. The miners stand within this square frame, where they work and erect more timber as they proceed. It frequently happens that the ore is so plentiful and rich in this kind of metallic repository, as abundantly to compensate for all the labour and expence.

Flat Veins and Beds.—When a vein runs parallel with the strata, it is called a flat vein. If the strata are soft, and the metallic matter is widely distributed, such veins do not differ from beds, being regular beds or strata impregnated with metallic matter. When flat veins run between hard strata, they are also liable to contractions, or *twitches*, and again expand, forming *pipes* or tubular masses of ore, which extend in an inclined position, having the same dip as the strata. Flat veins may be distinguished from beds by this character; proper flat veins appear to be openings between the strata which have been filled with metallic matter from a rake-vein, or are at least connected with it, as they seldom are productive of ore, except in the vicinity of the vein; whereas beds are regular strata, having the same elevations and depressions as the other strata in a mountain, but containing metallic matter more or less abundantly scattered through them. Iron ores and ores of manganese frequently occur in beds, forming regular parts or layers of the mountain. Other metallic ores, which occur less frequently and abundantly in beds, are, we believe, for the most part veins which have taken the course of the softer beds and distributed their contents through them. It is well known, that when a vein descends through strata of different kinds of rock, it grows wider in the soft strata, and contracts in the harder beds of rock.

The metalliferous beds in Cumberland appear, in many instances, to be soft beds, rendered productive of ore by a number of small veins running through them. There are few metallic beds in England, except in that county. Manganese occurs in beds in red sand-stone in the vicinity of Exeter, but the metallic matter decreases as the beds dip from the surface. Metallic beds, in primary countries, occur most frequently among the schistose mountains, composed of gneiss, mica-slate, and slate. (See ROCK.) It is observed, that the ores and minerals which occur in beds are seldom crystallized, as these beds contain few druses or

cavities to admit the formation of crystals. The minerals in beds are accompanied with garnet, actinolite, and hornblende, which never occur in rake-veins. See GARNET, &c.

Stock-work.—When a rock is crossed and penetrated by a great number of small veins in every direction, the whole mass is worked as an ore, and is called by the Germans a stock-work, or werke, the rock being afterwards separated from the ore by pounding and washing, in the same manner as the vein-stone is cleared from the ore in other mines. When the ore is disseminated in particles through the rock, such rocks are also worked for the ore when it exists in sufficient quantity. In some instances, masses of ore of great magnitude are found imbedded in rocks, without any apparent connection with veins, which masses must have been formed at the same time with the rock itself.

Rocks and strata are sometimes penetrated by metallic salts or oxyds, diffused through the mass in the same manner as we frequently observe strata of sand-stone abounding with the red oxyd of iron. Where the metals are valuable, such impregnated rocks or strata are sometimes worked as ores. At Alderley Edge, a hill near Macclesfield, in Cheshire, the sand-stone, which is in some parts a kind of breccia, is impregnated with the black oxyd of cobalt, with the carbonate and oxyd of copper, and with particles of sulphuret and carbonate of lead, and has formerly been worked for the lead and copper, and more recently for the cobalt. Mr. Williams, in his "Natural History of the Mineral Kingdom," describes a singular stratum of stone near Loflymouth, in the shire of Moray, of about eight feet thick, which is composed of several species of hard and fine stones of various beautiful colours. "This stratum is a kind of pudding-stone, in the composition of which there is blended about an eighth part of good blue lead-ore or galena.

"This curious bed of stone is nearly horizontal, but dips away with an easy slope towards the north of the Moray Frith. The lead is found in larger and smaller grains and flowers, blended through the whole body and composition of the stone, in the same manner as the small masses of agates and coloured crystals, and other species of stone, are found blended through the whole body of the stratum."

Where metallic ore is thus intermixed with fragments of rock forming a conglomerate or breccia, it may probably be referred to the same kind of metallic repository as stream-works, (see *Stream-Works*), in which particles and masses of ore are intermixed with loose pebbles and sand, forming beds at the bottom of valleys, or on the sea-shore, the metallic matter, as well as the pebbles, being derived from the disintegration of rocks containing metallic veins; but in the instance cited by Mr. Williams, the parts have become united, forming a solid stratum.

The manner in which metallic veins were filled with ore has greatly divided the opinions of geologists. George Agricola, a Saxon, who died in 1555, appears to have been the first writer who had any distinct knowledge of the structure of metallic veins, which he published in a work entitled "De Rê Metallica," and another work entitled "Bermanus." His theory of veins is in some respects similar to that of Werner, which has lately excited much attention. According to Agricola, the rents or fissures which are filled with metallic matter were partly formed at the same time with the rocks themselves, and partly afterwards, by the waters penetrating the softer parts; so that where there has been a larger quantity of water, or where the substance of the rock has been much softened, there the largest fissures occur. With respect to the earths and stones found in veins, he conceives the former to have been detached from the rocks and carried into the veins by water; the latter he considers as

arising from the earthy matter, hardened partly by change of temperature and partly by a lapidific juice. Minerals and metals he regards as being deposited from a solution in water, containing the earthy parts intimately mixed and combined with it in certain proportions. The solution of these mineral substances he conceives to have been greatly promoted by heat, on the abstraction of which they assumed their present solid form; the precious metals being the result of a more pure and perfect solution.

Becher, in his "Phyfica-Subterranea," published in 1669, ascribes the formation of metals and minerals to certain subterranean vapours which arise from the bowels of the earth, and penetrating the substance of veins, produce a peculiar change in the earthy or stony matter they meet with. He regards the earth as a hollow body, filled with clay, water, sulphureous and bituminous substances, from which arise certain exhalations that form the metals. The celebrated German physician Stahl, considers veins, as well as the substances they contain, to have been formed at the same time with the earth itself, and of course as being contemporaneous with the rocks they intersect; but he is disposed to attribute some effect to the action of air and other causes.

Henkel, in his "Pyritologia," has given an ingenious theory of the formation of metallic veins, which has been adopted, with certain modifications, by some later geologists: he attributes the formation of ores to a peculiar exhalation produced and engendered by fermentation, supposed by him to take place in the interior of rocks. The basis of each ore and mineral he supposes to exist in the substance of the rock, and by a peculiar process of nature it is matured and converted into the metal. He does not venture to ascertain the nature of these bases, but in one passage he treats of subtle earths, in another of mercurial, arsenical, and sulphureous parts. These three last he probably considered as constituent parts, and the metals as compounds. Air, water, and fire, are substances, according to this mineralogist, of which Nature avails herself in the formation of metals. He also supposes certain kinds of earths and stones to exist, which serve as the matrix for others, and which are indispensably necessary in the formation of minerals.

Zimmerman, the pupil of Henkel, is the first mineralogist who considers veins to have been formed by a transformation of the substance of the rock. Minerals, he says, are undoubtedly formed in the rock; but daily experience shews that the rock is not of itself capable of forming a metal, for were the mineralizing principle capable of converting it into a metal, we should find whole mountains which had undergone this change. But this change is only met with in certain directions, where the part of a rock, being thus transformed, constitutes veins. These veins, when they have not suffered an entire change, or when they do not contain perfect metals, are still of a different nature from the rest of the rock. An attentive examination will shew that they are of a decomposed and friable nature, appearing to have a tendency to return to this natural earthy state, from which we may conclude that these veins were originally the same as the rock, but that their texture had been altered and decomposed by some particular saline substance, which penetrated the rents and fissures, and had rendered them fit to be transformed into minerals.

Before noticing the theory of Von Oppel, which has since been adopted by Werner, we shall state the opinions of those geologists who, with Henkel and Zimmerman, suppose that veins have been filled by local causes which may still continue to operate; whereas Von Oppel and Werner conceive that they were formed by a general cause, the operation of which ceased before the present state of the globe. Lehman, in his

treatise on the matrices of metals, published in 1753, says, "the veins which we find in mines appear to be only the branches and shoots of an immense trunk, which is placed at a prodigious depth in the bowels of the earth, but in consequence of its great depth we have not been able to reach the trunk. The large veins are its principal branches, and the inferior ones the twigs. What I have said," he adds, "will not appear incredible, when we consider that the bowels of the earth are, according to every observation, the workhouse where Nature carries on the manufacture of the metals; that, from the beginning of the world, she has been working at, and elaborating their primitive particles; that these particles issue forth, in the form of vapours and exhalations, to the surface of the globe through rents, in the same manner as the sap rises and circulates through vegetables by means of the vessels and fibres of which they are composed."

The latter part of the theory of Lehman, which supposes that changes are now taking place in the interior of the globe, by which metallic ores are still forming, has been supported by many geologists, who have had opportunities of extensive observation. Mr. Von Trebra, sub-director of mines in Saxony, in his work entitled "Observations on the Interior of Mountains," advances a theory nearly similar to that of Zimmerman, and agreeing in part with Lehman. From the third letter of that work we make the following extract.

"In explaining the phenomena which are observable in the interior of mountains (it must however be remembered, that I do not include such as are evidently of volcanic origin), I do not avail myself of those great causes which, by their magnitude, the suddenness of their action, and by their effects, produce sudden changes which take place under our eyes, such as subterranean fires, earthquakes, and the like. I refer these phenomena to natural causes, which, though less evident and slower in their operation, are no less certain of producing a radical transformation. Of this kind are putrefaction and fermentation. It is of little consequence by what name we distinguish this peculiar action exerted by Nature in the mineral kingdom; it consists in an intestine motion in the central parts of the globe, and appears to be produced by water combined with heat in different degrees of intensity. I observe such changes still going on, and can conceive them to continue so long as the same series of operations exist in nature. I am persuaded that there is constantly going on in our mountains a variety of transformations, compositions and decompositions, which not only take place at present, but will continue to the end of time.

"Fermentation, if I may be allowed to call by that name this quality which acts by insensible degrees, produces the most perfect transformations in the bowels of the earth; fermentation I say may, according to my theory, alter the entire mass of a mountain; it may convert granite into gneiss, as this last only differs from the former in its structure, which is slaty or schistose; gneiss indeed has no other distinctive character than its structure, namely, the regularity and parallelism of its beds, and in some places a decomposed felspar approaching to clay. This fermentation may also convert greywacke into an argillaceous schist, which last may again by induration become jasper, when this process is either diminished or stopped. By it, also, quartz may be converted into clay, calcareous substances into quartz, and the whole mass of a mountain into inflammable or saline matter, or even into ores, metals, or semimetals. To it I ascribe the power of producing, preserving, and continuing to form the different beds and mineral repositories, which are found both in primitive and flötz mountains: finally, the effects which the waters produce in filtering from above to below, and which

in their passage through the different rocks may undergo some peculiar modification, appear to me the principal cause why this fermentation may act with more force in one part of the same mountain than in another."

Patrin, a celebrated French mineralogist, considers the changes taking place in the mineral kingdom, as effected by a process somewhat similar to secretion in the animal and vegetable kingdoms, and ascribes a kind of mineral life to the earth itself, differing perhaps as much from vegetable life as the latter differs from that of animals. According to this theory, each kind of mineral substance is capable of converting masses of mineral matter into its own peculiar nature, as animals convert their aliment into flesh and blood. Whatever may be thought of this theory, we believe that those who are most practically conversant with the various phenomena and transmutations that occur in mines, will readily admit that many changes are taking place, which cannot be explained on any known chemical or mechanical principles, and which bear a strong resemblance in their effects to the process of secretion. Nor can it, even in the present state of chemical science, appear improbable that the different earths and metals may be converted into each other by natural processes. The different beds of rock intersected by metallic veins, are themselves metallic substances combined with oxygen; or, in other words, all the rocks and strata which form the earthy parts of the globe, consist of oxygen combined with metallic bases; and as these metallic bases may perhaps be compounded of the same elementary parts united in different proportions, the transmutation of one earth or metal into another, may be effected by a simple change in the arrangement of the elementary molecules.

The theory of veins proposed by Von Oppel, and in part supported and extended by Werner, supposes veins to have been fissures originally formed by the desiccation of mountains, and the shrinking in of the mass. These fissures, being open at the top, were afterwards filled with their contents by metallic solutions poured in from above. Mountains, according to Werner, have been formed by a successive accumulation of different beds and layers, placed or heaped over one another. "The substance of these beds was at first wet, and possessed little solidity; so that when the accumulation of matter had attained a certain height, the mass of the mountain yielded to its weight, and must consequently have sunk and cracked. As the waters which assisted in supporting the mass began to retire, and lower their former level, these masses then lost their support, and yielded to the action of their weight, opening, and falling to the side where the least resistance was opposed. The shrinking of the mass of a mountain produced by desiccation, and still more the fractures by earthquakes, and other similar causes, may also have contributed to the formation of fissures.

"The same precipitation, which in the humid way formed the strata and beds of rock, furnished and produced the substance of veins. This took place when the solution, from which the precipitation was formed, covered the existing rents, which were as yet wholly or partially empty, and open in the upper part. Veins, whether considered as rents, or as the substance constituting the vein, have been produced at very different times; and the antiquity or relative age of each can be easily determined."

Such, in Werner's own words, are the great outlines of his theory, a theory which we conceive to be decidedly opposed by all the most striking appearances existing in the mineral kingdom, and equally opposed to the simplest known and acknowledged laws of nature. If metallic veins were once open fissures, filled by precipitations from a solu-

tion that covered the whole globe, with the highest mountains in which metallic veins are found; it is obvious that these metallic precipitations would be most considerable in the lower parts of the surface, in valleys and plains, where the fluid must have been much deeper than on the summits and sides of mountains. We ought, therefore, to find thick beds of metallic matter covering and incrusting the low and level parts of the globe; but nothing is more rare than to find beds of metallic matter in low plains. Where beds of metallic matter exist, it is always in comparatively high countries, abounding in veins; and it is much more probable that the beds and veins were formed by local causes, and not from a solvent covering the whole globe. The metallic parts of this metalliferous ocean must have possessed the greatest specific gravity, and instead of floating on the top of the fluid, to be deposited in the fissures of lofty mountains, it would have descended by the laws of gravity, forming crusts of different degrees of thickness from the bottom to the top, increasing downward. The reverse of this is the fact. It is principally in alpine districts, and at enormous heights, that metallic matter is accumulated in the greatest abundance. It is in the heights of the Cordilleras of Peru that the productive mines of Potosi are situated: it is in the same chain of mountains, more than 14,000 feet above the level of the sea, that the prodigious mass of mercurial ores is found at Guanaca Velica, where, in the space of two centuries, more than 15,000 quintals of this metal have been procured.

But the facts most opposed to the theory of Werner are those which we have stated, namely, that when a metallic vein passes through different strata, the mineral substances it contains generally vary in each stratum, either in kind or quality. So seldom an entire change takes place, as from tin to copper or lead; in other instances, the vein will contain the same kind of ore in the different strata, but it will be invariably richer or poorer in some of the strata than in others, and there will be certain strata in which scarcely any ore occurs. Very frequently where the same kind of metallic matter is contained in the vein, it will be mineralized or combined with different substances, as the vein passes through different beds: thus we find a metallic sulphuret more prevalent in one part, and a metallic salt or oxyd in another part of the vein.

In Derbyshire, where the veins of lead pass through different beds of mountain lime-stone, which alternates with beds of basaltic amygdaloid, provincially called toad-stone, it is found that the vein scarcely ever contains lead as it passes through the toad-stone, where it is always much narrower, and in some places appears to be entirely cut off by it; but on making into the under beds of lime-stone, the vein is found again, and is as productive as in the upper beds. Where the vein can be traced through the toad-stone, it contains calcareous spar, and sometimes a few particles of lead-ore. If veins had been filled from above by metallic solutions, it is impossible to conceive that the nature of the rock could change the quality of the ore; much less could the ore disappear in one stratum, and appear again in a stratum below it. Professor Jamieson, in a paper published in the *Memoirs of the Wernerian Society*, has attempted to explain the difficulty presented by the interruption of the veins in Derbyshire, on the supposition that the different beds of lime-stone and toad-stone, together with the metallic veins, were contemporaneous, and that the toad-stone cut through the veins at the period of their formation. On this hypothesis, Mr. Bakewell, in his *Introduction to Geology*, remarks: "The existence of different organic remains in the upper and lower beds of the mountain lime-stone in

Derbyshire, precludes the possibility of these beds having been all formed at the same time. The zoophytes in the lower beds of rock could not be living and co-existent with the shell-fish in the upper, nor with the vegetables, the remains of which are occasionally found in the sand-stone that covers the whole, and into which the veins sometimes shoot. Cuvier has well observed, that the existence of different organic remains in the upper and lower strata offers incontrovertible proofs that they were formed in succession over each other." In point of fact also, the veins are not always cut off by the toad-stone; but they are never productive of ore, where they pass through it, except in very small parties.

These facts are not less opposed to the igneous theory of metallic veins than to that of Werner. If metallic veins had been filled with their contents by the operation of subterranean fire, which cracked the surface, and injected the metallic matter in a state of fusion, it is impossible to conceive that the nature of the rock, through which the veins pass, could have produced any material change in the quality of the ore. Metallic ores may, in some instances, have been formed slowly by exhalations from subterranean fires; as specular iron-ore, and even gold, has been found in the craters of volcanoes; and the phenomena, presented by the lava which destroyed Torre del Grecco in 1794, indicate the manner in which such ores are formed. The lava had buried entire houses for more than twelve months, at the latter end of which time it had considerably cooled; and when the houses were opened, pieces of iron were found converted into a state of black, red, and magnetic oxyds, having the hollow parts and interstices filled with a brownish-red transparent oxyd of iron, and with specular iron-ore. In the articles made of iron, which had undergone this change, the external form was scarcely altered, which evinces that the crystals had been produced by sublimation. Copper articles were changed into crystallized red oxyd of copper, and red oxyd with green and blue carbonate. From the absence of metallic sulphurets, it is inferred that the lava contained little, if any, sulphur. These changes shew that metallic matter may be sublimed and converted into the state of ore by subterranean heat, at a much lower degree of temperature than has been supposed.

There is a circumstance on which those who contend for the aqueous formation of metallic veins have laid much stress. In some instances, rounded pieces of stone, apparently resembling water-worn pebbles, have been found in mines at a considerable depth; but as many veins contain hollow spaces, through which water is continually running, the formation of pebbles might admit of a satisfactory explanation, without supposing that these pebbles had fallen in from above. The pebbles which we have seen of this kind, from the mines in Cornwall, are all of a chlorite schistus, and the form oblate, presenting the appearance which may frequently be observed in rocks of the same kind. It is in all probability an original formation, and not a breccia from pre-existing rocks.

There is another circumstance which appears to have escaped the attention of geologists. The water in the mines of Cornwall, particularly in the vicinity of copper veins, has a temperature considerably above that of the natural temperature of the earth: it is said to be at 70° Fahrenheit; and the working miners, from its sensible warmth, can predict with certainty the vicinity of a copper vein. The increase of temperature, if any, in the vicinity of tin veins is less sensible.

From hence, as well as from various appearances in mines, we are led to infer that there are certain chemical changes

now going on in the interior of the earth; and it is from a more enlarged acquaintance with these phenomena, that we can alone expect to obtain a satisfactory theory of the formation of metallic veins.

The following is a summary account of the rocks and situations in which metallic ores are generally found.

Platina, and the recently discovered metals, palladium, rhodium, osmium, and iridium, have not been hitherto found in veins, but in the sands of rivers. The four latter metals are found as alloys in the grains of platina. See **PLATINA, PALLADIUM, &c.**

Gold and silver are found in veins, and disseminated in primary and transition rocks, in porphyry, sienite, and the lower sand-stone. Gold has been occasionally discovered in coal, and is very abundantly disseminated in the sands of some rivers. See **GOLD** and **SILVER**.

Mercury is found in slate, in lime-stone, and in secondary strata. See **MERCURY**.

Copper occurs in veins and beds in primary and transition rocks, in porphyry and sienite, and occasionally in sand-stone. Masses of native copper, of large size, are found on the surface of the ground, in the interior of North America. See **COPPER**.

Lead and zinc occur in veins, and disseminated in primary and transition rocks, except trap and serpentine, in the lower secondary strata, and in porphyry and sienite. See **LEAD** and **ZINC**.

Antimony occurs in veins in primary and transition mountains, except trap and serpentine.

Bismuth, cobalt, and nickel, occur in primary and transition mountains, except lime-stone, trap, and serpentine. Cobalt and nickel also occur in transition mountains, and in sand-stone. See **BISMUTH, &c.**

Arsenic occurs in veins, either as a sulphuret or mineralizer of other metals, in primary and transition mountains, and in porphyry. See **ARSENIC**.

Tellurium occurs in veins in porphyry, combined with gold. See **TELLURIUM Mines**.

Manganese occurs in beds and veins in primary and transition mountains, and in beds, and disseminated in red sand-stone. See **MANGANESE**.

Molybdena, tungsten, and titanium, occur in granite, gneiss, mica-slate, and argillaceous schistus. These metals, with chromium and cerium, are very rare, and can only be reduced to the metallic state with great difficulty. See **MOLYBDENA, &c.**

Mineral veins differ from metallic veins, being destitute of ores, and filled with the same substances which compose entire rocks, or with earthy minerals.

Quartz veins (see **QUARTZ**) resemble in their structure and position many metallic veins; and it not unfrequently happens that a vein, which contains metallic ore in one part, intermixed with quartz and other vein-stones, will, in another part, be entirely filled with quartz. Quartz veins intersect almost all primary and transition rocks, but are particularly abundant in rocks of argillaceous schistus and greywacke. (See **ROCK**.) The quartz in veins is most frequently white, and nearly opaque; and being much harder than the rocks which it intersects, it remains on the summits of mountains, after the surface of the rock is decomposed, until it is carried down by diluvial currents into the beds of rivers, where it becomes rounded by attrition, and is transported to distant districts. Most of the white quartz pebbles in England have probably been formed from the quartz veins of decomposed rocks, as no quartz of a similar kind exists as a rock in any part of England or Wales; but the same mineral abounds in veins.

Granite, argillaceous schist or slate, porphyry, greenstone, pitch-stone, basalt, and various other rocks, frequently form veins in mountains of the same kind with themselves, or in different rocks. Where a vein of one kind of rock intersects a rock of a similar kind, the substance of the vein generally differs from that of the rock in texture, colour, and other characters. The granite in veins, which passes through granitic rocks, will generally be coarser or finer grained than the rock which it passes through, and have the constituent parts differently mixed. The followers of Werner assert, that veins which contain rock substances have been filled from above by matter poured into the fissures, and that the granite in veins is of a secondary formation. They further maintain, that the lower rocks, which they consider as the older, never rise into the upper rocks in the form of veins. In opposition to this opinion, it has been discovered that veins of granite, in Cornwall, may be distinctly seen rising into the schist or killas which covers the granite rocks in many parts of that county, particularly at St. Michael's mount, east of Penzance, and at Mousehole, two miles west of that town. Where the junction of the granite and schist is exposed by the action of the sea, veins of the former rock may be traced, at low water, running in a zigzag form for many yards into schist, gradually growing narrower, and terminating in small branches and strings. One circumstance we observed in these granite veins at Mousehole, which may deserve notice: the same vein which penetrated the schist, when it entered the granite, was different in texture from the granite rock, though it had the same constituent parts; it might be distinctly traced for a considerable distance into the granite. The granite also, in the vicinity of the schist, was smaller grained than the general body of the rock; and the schist, where in junction with the granite rock or granite veins, was changed to a kind of very fine-grained gneiss. These facts seem to indicate that both the granite and the schist, to a considerable distance from their junction, had been in a softened state at the same time, and that their consolidation was contemporaneous. Similar appearances, with an intermixture of veins of schist in granite, are presented at Glentilt, and other parts of Scotland. Veins of granite, porphyry, or schist, never penetrate the upper secondary strata; but veins of basalt and trap (see **TRAP**) have been found in every kind of rock, even penetrating chalk. These veins are sometimes of vast extent and width, and frequently occasion great dislocations and derangements in the stratified rocks, particularly in the coal strata, where they have been most observed: hence they are called faults. (See **FAULT** and **STRATA**.) The dislocation of the strata by a vein of this kind is represented in *Plate II Geology, fig. 8*, where the different strata, *c, d, e, f, g*, on the left-hand side, are separated from the corresponding strata on the right, and considerably elevated.

As the veins of trap or basalt are nearly vertical, and often several yards in width, and the substance with which they are filled being frequently harder than the strata which they intersect, these veins remain when the surface is decomposed to a considerable depth, rising like a wall or fence, which, in the language of North Britain, is synonymous with *dyke*; hence such veins have been called *dykes*, or *whin-dykes*, the term whin-stone being used to denote basaltic rocks. (See **WHIN-STONE**.) Basaltic veins, or whin-dykes, vary in width from a few inches to several yards, and are sometimes more than one hundred yards wide. They often extend many miles in length; in other instances they terminate at shorter distances, forming irregular wedge-shaped masses. When basaltic dykes are of considerable

width, the basalt is intersected by fissures; and sometimes the central parts and sometimes the sides are harder or softer than the other; and in some parts the basalt graduates into a dark ferruginous clay. Masses of basalt from the dyke are frequently found wedged in between the strata, extending to some distance: and where basaltic dykes intersect coal strata, the coal in the immediate vicinity of the dyke has frequently the appearance of being charred. At Corkfield-fell, in the county of Durham, the coal strata are cut through by a basaltic vein or whin-dyke, which is about seventeen yards wide. Where it comes in contact with the coal, the latter substance, for several feet, is converted into a pulverulent state, like foot. At a greater distance from the basalt, the coal is reduced to a coke or cinder, which burns without smoke, and with a clear durable heat. At the distance of fifty feet from the basalt, the coal is found in the state of common mineral coal. The roof over the coal is lined with bright crystals of sulphur, probably sublimed by heat from the pyrites common to coal. In these appearances we recognize every circumstance which might be expected from the agency of heat, but which would be extremely difficult to reconcile with the aqueous formation of basalt. We have seen similar appearances near basaltic dykes in Northumberland. The vein, or dyke, of basalt at Cockfield-fell, is part of the longest dyke which has been traced in England, or perhaps in any other country. According to the description of it in Mr. Bakewell's *Introduction to Geology*, "it extends from the western side of Durham in an eastward direction, to Bewick in Yorkshire, crossing the river Tees at this place, and proceeding in the same direction through the Cleveland hills, in the East Riding of Yorkshire, to the sea-coast between Scarborough and Whitby. It rises to the surface, and is quarried, in many parts of its course, for stone to repair the roads. It crosses the turnpike near the seven mile-stone from Whitby to Pukering, where there is a quarry sunk in it. The vein, or dyke, is here about ten yards wide; the stone is a dark greyish-brown basalt, and is the principal material for mending the roads in the district called Cleveland. The extent of this dyke has been traced in a direct line about seventy miles. In its course it intersects the metalliferous lime-stone of Durham, the coal district, and the aluminous schistus. The circumstances attending this and other extensive dykes, which have not hitherto been regarded by geologists, completely invalidate," says Mr. Bakewell, "the theory, that these dykes were originally open fissures, formed by the drying or shrinking in of the rocks. As the different rock formations through which it passes contain different organic remains, they must have been formed in succession at different periods, and the metalliferous lime, with the lower strata, must have been consolidated long before the upper strata were deposited; and the causes which might dispose the upper strata to shrink and open, cannot be supposed to act on the lower rocks. It is also remarkable, that the width of this vein is more than twenty yards in the lower rocks on the west; but in the upper rocks it is not more than ten yards. The dyke must have been filled with its contents at the time of its formation, otherwise it would contain fragments of the rocks which it intersects. As it passes through the lime-stone, it has rendered it more crystalline in its vicinity, and the effects in charring the coal, before described, point to subterranean fire as the original cause of its formation, and as the source whence the basalt that fills it was supplied. The close resemblance between the basalt and compact lava, add probability to the opinion that this great dyke was originally formed by an expansive force operating from

below, which opened a chasm in the surface of the earth, and ejected the contents in a state of fusion. A volcanic dyke was formed on the western side of Vesuvius, June 12, 1794, two thousand three hundred and seventy-five feet in length, and two hundred and thirty-seven feet in breadth, through which lava rose to the surface. This lava, when cooled, formed a wall of stone intersecting the former beds of lava, and constituting a real dyke. The stone has a dark-grey colour, and is in some parts so compact as to resemble horn-stone." See VOLCANO.

The effects of basaltic veins on the contiguous parts of the strata of sand-stone which they intersect, are no less remarkable. In some instances, the sand-stone appears very considerably indurated, and converted into a substance resembling horn-stone.

It is observed by Mr. Allan, *Transactions of the Royal Society of Edinburgh*, vol. vii. that the sand-stone which is thus indurated, contains calcareous earth, which appears to have promoted its semi-vitrification; but where the sand-stone remains unchanged in the vicinity of a dyke, the calcareous earth is wanting. Sir G. Mackenzie observed basaltic dykes in Iceland, the walls or sides of which were lined with a glassy substance resembling obsidian. These effects offer further illustration of the igneous origin of basaltic veins. A very interesting account of the effect produced by basaltic veins on the different beds of rock at the Giants' Causeway, and on other parts of the same range on the north coast of Antrim, is given in the third volume of the *Transactions of the Geological Society*.

Various beds of columnar basalt, argillaceous lime-stone, and chalk, are intersected by perpendicular dykes or veins of basalt. The chalk in the vicinity often undergoes a remarkable change, extending eight or ten feet from the wall on each side, and thence gradually decreases. The part nearest the basalt is converted into a dark-brown crystalline lime-stone, like coarse-grained primitive lime-stone. The next strata is that of finer-grained primitive lime-stone, or saccharine lime-stone; then fine-grained arenaceous lime-stone. A compact variety, having a porcelain aspect, and a blueish-grey colour, next succeeds; this, towards the outer edge, becomes gradually white, and insensibly graduates into unaltered chalk. The flints in the altered chalk assume a greyish-yellow colour. The altered chalk is highly phosphorescent when subjected to heat. In other parts of the range, the argillaceous beds of lias appear converted into horn-stone by contact with the basalt, and contain in that state the imbedded fossils peculiar to the lias stratum. (See STRATA.) The basalt in some of the veins is columnar; but the columns lie horizontally. It has been conjectured, with some probability, that this has been caused by its passing from a state of igneous fluidity, and the refrigeration commencing from the sides. From the same cause, in the beds of columnar basalt in that range, (see GIANTS' Causeway,) the columns are perpendicular, the cooling commencing from the top and the bottom of each bed. The marine organic remains in the strata over the basalt, prove that the whole were formed under the sea. In some instances, basaltic veins appear to have been opened, and the intervening space filled with debris from the upper strata; and there are basaltic dykes in Northumberland, in which the basalt being divided into irregular masses, the interstices are filled with iron-clay, and contain impressions of ferns, like those in the coal strata which these dykes or veins intersect. On the whole, no country in the world which has yet been examined presents so many interesting appearances of basaltic veins as the northern parts of Great Britain and Ireland, nor are they any where exposed to the

eye of the observer with so much distinctness as on many parts of the sea-coast, where the ocean has bared the surface, and exposed the most magnificent and instructive sections of entire mountains, penetrated by these veins to the height of many hundred feet. The veins may often be seen extending from the mountains into the sea, rising up like enormous walls, which serve as monuments of the ravages of the ocean upon the coast. The great hardness of the substance which fills the veins has prevented their destruction by the waves that have broken down and removed the mountain masses in which these veins were once imbedded.

Messrs. Lewis and Clarke, the American travellers, describe extensive walls of dark columnar stone ranging through the interior of North America: these walls were undoubtedly dykes or veins of columnar basalt, remaining where the surface of the ground had been washed away. There are also instances where the substance of basaltic veins has been

softer than the surrounding rock, and is washed out wherever the rock is exposed, forming deep fissures, with perpendicular walls of rocks on each side. Such appearances are not uncommon on the sea-coast in various parts of Scotland. For an account of basaltic rocks, see TRAP.

VEIN is also applied to the streaks, or waves, of divers colours appearing on several sorts of woods, stones, &c. as if they were really painted; and which the painters frequently imitate in painting wainscots, &c.

Marble is generally full of such veins.

Lapis lazuli has veins like gold. Ovid, speaking of the metamorphosis of men into stones, says—"Quæ modo vena fuit, sub eodem nomine manet."

Veins, in stones, are often a defect, proceeding usually from an inequality in their consistence, as to hard and soft: which makes the stone crack, and shiver in those parts.

Verdegrease

VERDEGREASE, VERDIGREASE, *Verdegris*, or *Verdigris*, a kind of rust of copper, formed from the corrosion of copper by a fermented vegetable, and into a blueish-green substance, of great use among painters for a green colour.

The word is formed from the Latin, *viride eris*: it is also called *erugo*. Others call it the *flower*, and others the *viridic salt of copper*; though, in reality, it is rather the proper substance of the metal.

The greatest quantities of verdigris have been manufactured at Montpellier, the wines of Languedoc being very proper for this preparation; and it has been exported thence in cakes, each weighing about twenty-five pounds. The following process for making it is described by M. Monet, of the Royal Society of Montpellier, and is published in the Memoirs of the Academy for the years 1750, and 1753. Vine-stalks, well dried in the sun, are steeped during eight days in strong wine, and afterwards drained. They are

then put into earthen pots, and wine is poured upon them; the pots are carefully covered; the wine undergoes the acetous fermentation, which in summer is finished in seven or eight days, but requires longer time in winter, although the operation is always performed in cellars. When the fermentation is sufficiently advanced, which may be known by observing the inner surface of the lids of the pots, which during the process of the fermentation is continually wetted by the moisture of the rising vapours, the stalks are then to be taken out of the pots: these stalks are by this method impregnated with the acid of the wine, and the remaining liquor is but a very weak vinegar. The stalks are to be chained during some time in baskets, and layers of them are to be put into earthen pots with plates of Swedish copper, so disposed, that each plate shall rest upon and be covered with layers of stalks. The pots are to be covered with lids,

and the copper is thus exposed to the action of the vinegar, during three or four days, or more; in which time the plates become covered with verdigris. The plates are then to be taken out of the pots, and left in the cellar three or four days; at the end of which time they are to be moistened with water, or with the weak vinegar above-mentioned, and left to dry. When this moistening and drying of the plates have been thrice repeated, the verdigris will be found to have considerably increased in quantity, and it may be then scraped off for sale.

A solution or erosion of copper, and consequently a verdigris, may be prepared by employing ordinary vinegar instead of wine, as directed in the above process. But it will not have the unctuosity of ordinary verdigris, which is necessary in painting. Good verdigris must be prepared by means of a vinous acid or solvent, half acid and half spirituous. Accordingly, the success of the operation depends chiefly on the degree of fermentation to which the wine employed has been carried; for this fermentation must not have been so far advanced, that no sensibly vinous or spirituous part remained in the liquor. Macquer's Dict. Chem. See the process as described by Chaptal, under the article COPPER.

The Society of Arts, &c. offered a premium in 1756 for the making of verdigris in England; and in 1760 intimated, that it might be made by moistening with the cheapest and worst sort of cyder, the marc or remains of apples, pears, gooseberries, currants, sloes, crabs, blackberries, or any fruits deprived of their juice by expression, proceeding afterwards by the process above described. The premiums offered by the Society were several times claimed and allowed; and it was resolved, in 1763, that verdigris actually made of British materials, and submitted to various trials, was even superior to the foreign. Accordingly, a considerable manufactory was established, and successfully carried on for the purpose of making verdigris.

The goodness of verdigris is judged of from the deepness and brightness of its colour, its dryness, and its forming, when rubbed on the hand with a little water or saliva, smooth paste, free from grittiness. This concrete is partially dissoluble in water and rectified spirit, and almost totally in vinegar; from the acetous solution, well saturated, and left to exhale slowly in a warm air, the greatest part of the verdigris may be recovered in a crystalline form, called *distilled verdigris*. See CRYSTALS of Venus, and COPPER.

The crystals, distilled with a suitable fire, in a retort or other like vessel, give over the acetous acid in a highly concentrated state, but somewhat altered by the process. See ACETIC Acid.

The matter which distilled vinegar leaves undissolved, on

being mixed with some borax and linseed oil, and fluxed in a crucible, yields a brittle metallic substance, of a whitish colour, not unlike bell-metal. Neum. Chem. by Lewis, p. 64, n. a.

Verdigris is employed externally for detaching foul ulcers, and as an escharotic; but it is seldom used, though milder than the sulphate or blue vitriol. It is employed as a collyrium in chronic ophthalmia. Hoffman recommends it particularly for destroying the callosities of old fistulæ; tents of powdered verdigris, made up with saliva, or other liquids, not fat or oily, consume, he says, the hardest callus in three or four days, so as to render it completely separable. A detergent ointment, called *mel ægyptiacum*, is prepared by boiling five parts of verdigris in fine powder with sixteen of honey, and seven of vinegar, till reduced to a clear consistence. The thinner matter which floats on the top of this mixture, after standing for some time, is generally used, unless it be required more acid; in which case, the thick part which has subsided is shook up among it.

In the Edinburgh dispensatory, an ointment, called *unguentum ex arugine*, has been directed, composed of white wax and resin, each two ounces, olive oil one pint, and verdigris half an ounce. When these kinds of applications are employed for venereal or other ulcerations in the mouth or tonsils, great caution is necessary, lest they should pass into the stomach; in which case, dangerous and even fatal consequences may ensue.

Verdigris is rarely or never given internally. It has been reckoned tonic, and administered with this view in a dose under gr. ss. Some recommend it, in the dose of a grain or two, as an emetic, which produces almost instantaneous effect, where poisonous substances have been taken, for the immediate rejection of them. But warm water, milk, and oils, are much less dangerous, and more proper. In too large doses, it quickly proves fatal; and, on dissection, the coats of the stomach appear much thickened, and of a green colour. Lewis's Mat. Med.

M. Navier has lately evinced the salutary effects of liver of sulphur, and particularly of liver of sulphur of Mars, as an antidote against the poison of verdigris.

Verdigris makes a blue-green colour in paint; but is generally used in yellow, which, by a proper mixture, renders it a true green. It is bright when good; but soon flies, when used in oil. When dissolved in vinegar, it is used in water painting, and is more durable; it may be also dissolved in the juice of rue, and thus produces a fine full green colour, equally fit for washing with that dissolved in vinegar.

Verdigris, with a decoction of logwood, strikes a deep black, which, when diluted, becomes a fine blue. See DYEING.

Vernier

VERNIER, is a graduated index which subdivides the smallest divisions on any straight or circular scale, in the reading of which greater accuracy is required, than can be obtained by simple estimation of a fractional part, as indicated by a pointer, or fiducial edge. The vernier was first invented by Pierre Vernier of Franche Comté, and made known to the world at Bruxelles (or Brussels) in the year 1631, through the medium of a pamphlet entitled "La Construction, l'Usage, et les Propriétés du Quadrant nouveau de Mathématique," &c. It gained the preference over the scale of Nonius, which was a circular diagonal scale, and which by some writers is yet confounded with a Vernier's index, though there is no greater resemblance between the two, than exists between the dial of a clock and the hand that points to it. The vernier is applicable to any straight or circular line, provided the divisions be equal; but the contrivance of Nonius was in the graduated line or scale itself, and required the aid of a fiducial edge as an index. We have given the representation of a *vernier* in several of our astronomical plates, when we were describing CIRCLE, EQUATORIAL, QUADRANT, TRANSIT-Instrument, and THEODOLITE, therefore it will not be necessary to introduce any other figure for the purpose of illustration; particularly as the principle of its application can be made clearly intelligible by either arithmetical or algebraical notation. Let us suppose two lines, either straight or portions of circles, to be exactly alike in dimensions, one called A, and the other B, and let one of them be divided into more equal parts than the other by unity; then will the difference of any two of the equal parts of the two lines, or arcs respectively, be a fraction, the numerator of which is the common length of the equal lines, or arcs, and the denominator the product of the numbers of parts into which each is divided. For if we put A for the common length of the equal lines, or arcs, with n and $n + 1$ for the equal parts into which each is divided respectively, the length of the divisions of each will

be $\frac{A}{n}$ and $\frac{A}{n + 1}$, and their difference $\frac{A}{n} - \frac{A}{n + 1}$

$$n \times n + 1$$

To exemplify this principle in an arc of small radius, let each degree be divided by an engine into three parts, of each 20', and let it be required that the vernier shall read to the accuracy of one minute; in this case the short scale of the vernier must be divided into 20 parts, and the equal arc

on the limb of the instrument either into 21 or 19 parts, so that the difference of the two equal arcs, in divisions, may be = 1; if 21, the former number, is adopted, the reading will be in a backward direction; but if the latter (*viz.* 19), it will be forward; let the arc on the limb be 6° 20', and let each degree be divided into three parts, of 20' each; also let 19 be the number of such parts or divisions; and let the equal arc on the vernier be divided into 20 equal parts; then $n = 19$, and $n + 1 = 20$ will make a difference between a single division of the limb, and one of the vernier

$$= \frac{6^\circ 20'}{19 \times 20} = \frac{380'}{380} = 1', \text{ as was required. This difference}$$

becomes the index for subdividing the smallest divided space of the limb, and it is ascertained how often it must be taken, by inspecting the place on the divided vernier, where a stroke on it exactly coincides with a dividing stroke on the divided limb of the instrument; for instance, if the zero, or stroke marked 0, be the coincident one, the reading may be had from the divisions of the limb only, without any addition from the vernier; but if the coincidence happens at any other place, say at stroke 5, stroke 8, or stroke 10, as numbered on the vernier, then 5', or 8', or 10', as the case may be, must be added, as the measure of a fractional part of a division, to the measure read from the divisions only, that are contained between zero on the limb and zero on the vernier: the difference, which we have said is = 1' when taken once, is 5' when taken five times, and 8' when taken eight times; and as the point of coincidence can never be mistaken, wherever it may fall, it will always determine how many minutes must be added for the fractional portion of a division, that zero of the vernier has advanced into an entire division; and as the eye will form a rough judgment at once, whether zero of the vernier is near $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or $\frac{1}{4}$ of a space on the limb, this notice will at once guide the observer to that part of the vernier's scale, where the coincidence will be immediately found; for as zero of the vernier advances in any division of the limb, by the slow motion of the tangent-screw of any instrument, the point of coincidence of the strokes of the two arcs advances with it, till the stroke at zero becomes itself coincident with a new dividing stroke of the arc on the limb, which coincidence denotes the addition of another 20', in our example, without reference to the vernier: but should there be any doubt about the exactitude of the coincidence, 20'', 30'', or 40'', may be taken instead of the last minute, accordingly as the eye can best judge of

the small quantity short of perfect coincidence; and examining the places of the preceding and following strokes will greatly assist in forming this judgment.

If we were to substitute 21 for 19 spaces on the limb, the result would be the same, with the inconvenience of reading backwards, and of subtracting instead of adding;

for $\frac{7^\circ}{21 \times 20} = \frac{420'}{420} = 1'$, as before; but instruments of

modern construction are exempt from this inconvenience, by having always one more division on the scale of the vernier, than on the equal arc of the limb.

In Troughton's snuff-box sextant, which is a very convenient instrument for the pocket, the radius of the divided arc is only about $1\frac{1}{4}$ inch, and the degree is divided, therefore, into two spaces only, so that $30'$ are necessarily indicated by the vernier; and as 29 spaces on the limb are taken equal to 30 on the vernier, the smallest quantity indicated

is $\frac{14^\circ 30'}{29 \times 30} = \frac{870'}{870} = 1'$, as before; and the reading of the

coincidences that indicate the last $30'$ is progressive, like the reading on the limb of the instrument.

In the common ebony sextant, the degree is sometimes divided into four parts, by reason of the increased length of the radius; consequently, when the reading is in a forward direction, fifteen divisions on the vernier occupy the same arc as fourteen on the limb; and the smallest quantity indicated thereby is

$\frac{3^\circ 30'}{14 \times 15} = \frac{210'}{210} = 1'$; but the brass sextants made and

divided by the best makers, have the minute subdivided into twenty, fifteen, ten, or even five seconds, according to the length of the radius, by means of a vernier with divisions and subdivisions, acting with divisions and subdivisions on the limb, which is a refinement of the original invention, introduced by Troughton, in consequence of the superior excellence of modern dividing. We have now before us one of Ramsden's best brass sextants of $9\frac{1}{4}$ inches radius, on the limb of which the degree is divided into three parts, and 40 divisions on the arc of the vernier measure 39 divisions

on the limb; therefore $\frac{13^\circ}{39 \times 40} = \frac{780'}{1560} = \frac{46800''}{1560} = 30''$

is the smallest quantity that the vernier will indicate, and every alternate stroke thereon counts one minute as the coincidence advances. This mode of reading the vernier doubles its former accuracy. But on the limb of this same instrument, the late Mr. W. Walker prevailed on Mr. Troughton to divide a second arc, within the former, which by our measurement is only of nine inches radius: in this inner arc, which reads with the inner arc of the vernier, the degree is first divided into halves, and then each half is subdivided into five smaller divisions, by shorter strokes very delicately cut, so that the degree is divided into ten small spaces, of $6'$ each, which are to be read before the vernier's subdivision of one of these spaces is examined. On the scale of the inner vernier are 72 small divisions, co-extensive with 71 on the limb; and as each of these is $6'$, we have $71 \times 6' = 426'$, or 25560'' for the whole arc of measurement: consequently $\frac{25560''}{71 \times 72} = \frac{25560''}{5112} = 5''$ is the smallest quantity that can

be indicated by such a vernier, and accordingly we observe on the scale of the Vernier twelve small or subdividing spaces between each minute stroke; *i. e.* every twelfth stroke is a long one, and they are numbered 1, 2, 3, &c. up to 6, which is the value of one of the smallest divisions on the limb, and

consequently the value of each subdivision on the scale is $\frac{1}{12}$ of $1'$, or $5''$: and yet, by the help of a high magnifier, placed in the centre of an illuminating reflector of plaster of Paris, this small quantity may be clearly discriminated. When Ramsden first saw this wonderful application of the powers of the dividing engine, he called his workmen together, to witness what he at first considered the folly of attempting greater accuracy than was practicable; but a close examination of the divisions convinced him, that his preconceived opinion had flood in the way even of his own improvements.

Sometimes a divided head or nut has been fixed on the end of the tangent-screw of slow motion, particularly by the older makers of pillar and mural astronomical quadrants, in order to subdivide the divisions of the vernier, as may be seen at Greenwich, Richmond, and other observatories; but when this apparatus has been in use some time, the parts become loose and inaccurate, even allowing that the measuring screw itself can be considered as perfect in all respects. On an examination of some of Graham's, the Sissons' and Bird's quadrants, we find that though the accuracy of $1''$ is professed by the construction, yet very little dependence can be placed on such profession after the parts have been for years in use. Of this conclusion Ramsden was no doubt sensible, when he introduced into his larger instruments the microscopic readings, with a good screw at the focus of the eye-piece of a compound microscope, where there is not so much stress on the screw as at the periphery of the arc, where the screw forms also a part of the clamping apparatus. To this adoption of the use of a compound microscope, in conjunction with the subsequent improvements in the art of dividing, much of the claim to superior excellence in our English astronomical instruments is to be attributed, which claim is still further supported by the invention of the achromatic object-glasses and improved eye-pieces of the telescopic portion.

Hitherto we have considered the principle and application of a single vernier only, which is in itself an useful and beautiful contrivance; and, as we have said, may be applied with advantage to subdivide a straight line; as, for instance, the scale of a barometer into hundredth parts of an inch, or the scale of Dollond's divided object-glass micrometer into the five-hundredth parts, or more; but with an entire circle that is graduated all round, the accuracy of an observation is greatly augmented, nay ensured, by the use of different verniers reading at different parts of the limb at the same time. At first two diametrically opposite verniers were introduced, as has been asserted, by one of the Sissons, though, we understand, not with a view to reading at opposite sides of the circle, by way of correcting the observation by an average; seeing that the remote end of the vernier bar had only a single stroke answering to zero of the other; but subsequently, in transit and other instruments used with a spirit-level, the double vernier became a valuable appendage, particularly when the construction of the instrument admitted of inversion of the position of the axis, so as to procure a double observation; and thence the true zero of the graduation of the measuring limb. This useful property was extended, we believe, by Troughton, first by introducing four, and then, with equal advantage, three equidistant verniers of similar powers. We have shewn the great use of additional verniers, at considerable length, under our article CIRCLE, particularly with respect to the property that three possess of correcting for the excentricity as well as inequality of the divisions of a circular instrument; and that as great accuracy may be expected from one *crossed* observation with Troughton's reflecting circle, or from a pair of *reversed* observations with a theodolite, with either circle, that has three verniers, as can be obtained by

a repetition of observations on the repeating circle ; for, by the mode in which Troughton's circular instruments are used, the readings will be had at six different points of the circle, though very little time is expended in making the observations. It is hardly necessary to add here, that when an instrument is of the reflecting kind, its divisions are doubly numerous for the same radius, when compared with an instrument that measures only by direct vision ; and that therefore the divisions on the vernier must be calculated to have their dimensions accordingly. In Troughton's reflecting circle of five inches radius, the degree is divided into three parts, and fifty-nine of these are commensurate with sixty on the scale of each of the three verniers ; therefore the excess of a space on the limb over one on the vernier is

$$\frac{40'}{60} = \frac{70800''}{3540} = 20'', \text{ which is the smallest quantity}$$

that a single vernier will indicate ; but as there are six readings in the crossed observation, which observation annihilates the errors of zero, and of the darkening glasses when used, it is to be inferred that the result will be accurate to

$$\frac{20''}{6}, \text{ or little more than three seconds, if we disregard the}$$

probable errors of reading, and of taking contacts in the observation, common to all instruments. The figures of the vernier scales in this circle count both ways, from each end, because the figures read both to the right and left of

zero on the limb, but there can be no mistake if the figures of the vernier are counted the same way that the limb of the circle reads. Formerly the zero of the vernier was placed at the middle of its scale ; and when it read out at one end, it commenced at the other, and finished again in the middle ; but this method, being liable to misapprehension, is now discontinued.

In an eighteen-inch astronomical circle, by Troughton, at present under our examination, which has four verniers at equal distances, and turns in azimuth, the degree is divided by Engine into twelve divisions, of which 59 fill the same arc as 60 on the verniers respectively ; hence we have $59 \times 5' = 295'$, or $17700''$ for the numerator, and $59 \times 60 =$

$$3540 \text{ for the denominator, and } \frac{17700''}{3540} = 5'', \text{ the smallest}$$

quantity that one vernier will indicate ; and accordingly the space between zero and $1'$ on the vernier is subdivided in 12 smaller spaces, so that each successive coincidence will mark out $5''$ on each separate vernier ; but as there are four verniers, and as the circle will reverse in position by means of the azimuthal motion, there will be virtually eight readings from which to take an average of $5''$, so that the probable accuracy resulting from such average comes *within the second*, and would have done so if there had been only three verniers. Hence the advantage gained over the average of the verniers by microscopic readings, is probably not so great as is generally supposed.

Vinegar

VINEGAR, ACETUM, an agreeable, acid, penetrating liquor, prepared from wine, cyder, beer, and other liquors, and varying in hue from light red to brown straw-colour, malt vinegar being more highly coloured than that of wine: and of considerable use, both as a medicine and a sauce: or, vinegar is a vegetable acid liquor, produced by the second degree of fermentation, or that which succeeds the spirituous, and is called the acid or acetous fermentation. Every liquor, which has completely undergone the spirituous fermentation, is spontaneously and necessarily disposed to the acid fermentation. Accordingly, every vinous liquor does continually tend to become vinegar, and is actually changed into it, sooner or later, according to circumstances; unless this change be prevented by some obstacle to fermentation in general. If vinegar be long kept, and particularly if it be exposed to the air, it will become muddy and ropy, acquiring an unpleasant smell, losing its acidity, and putrefying. In order to preserve it for a longer time, it should be boiled for a few minutes, so that the gluten may coagulate and separate, on the presence of which these changes depend, and also kept in well-corked bottles.

The word is French, *vinaigre*; formed from *vin*, wine, and *aigre*, sour.

The method of making vinegar has long been kept a secret among the people of that profession; who, it is said, oblige themselves to each other by oath not to reveal it; but, notwithstanding this, the Philosophical Transactions, and some other late writings, furnish us with approved accounts of it. Whatever be the materials used in the preparation of the liquor for producing vinegar, it is merely necessary to admit air into the vessel in which it is kept, and to preserve it in a temperature somewhat higher than that of the atmosphere in this climate, that is, from about 75° to 80°. When a liquor already fermented is used, it is also of almost indispensable importance that yeast, or some other ferment, be added, in order to hasten the fermentation, or else the change will be too gradual to obtain vinegar in perfection, and the first acetified portion will turn mouldy before the last has become sour. But if the material employed has not undergone fermentation, the whole process of the vinous and preceding acetous fermentation will go on without interruption, with the same ferment which first set it in action, as, *e. g.* in making vinegar from malt, or from sugar and water. It is necessary also to stop the process of the manufacture in that stage of it, in which the acid has attained to its highest degree of strength and perfection, after which the liquor would then speedily be deteriorated, the acetous acid would gradually disappear, and an offensive mouldy watery liquor remain, with scarcely any acidity. It depends upon the skill and experience of the manufacturer to determine when his vinegar is in a fit state to be drawn off and closely barrelled.

VINEGAR, Method of making Cyder. The cyder (the meanest of which will serve the purpose) is first to be drawn off fine into another vessel, and a quantity of the must, or pouze of apples, to be added; the whole is then to be set in

the sun, if there be a conveniency for the purpose; and, at a week or nine days end, it may be drawn off.

VINEGAR, Method of making Beer. Take a middling sort of beer, indifferently well hopped; into which, when it has worked well, and is grown fine, put some rape, or husks of grapes, usually brought home for that purpose; mash them together in a tub; then, letting the rape settle, draw off the liquid part, put it into a cask, and set it in the sun as hot as may be; the bung-hole being only covered with a tile, or slate-stone; and in about thirty or forty days it will become a good vinegar, and may pass in use as well as that made of wine, if it be refined, and kept from turning musty.

Or, vinegar may be made thus: To every gallon of spring-water, add three pounds of Malaga raisins; which put into an earthen jar, and place them where they may have the hottest sun from May till Michaelmas; then pressing all well, tun the liquor up in a very strong iron-hooped vessel, to prevent its bursting: it will appear very thick and muddy, when newly pressed; but it will refine in the vessel, and be as clear as wine. Thus let it remain untouched for three months, before it be drawn off, and it will prove excellent vinegar.

VINEGAR, To make Wine. Any sort of vinous liquor, being mixed with its own fæces, flowers, or ferment, and its tartar first reduced to powder; or else with the acid and austere stalks of the vegetable from whence the wine was obtained, which hold a large proportion of tartar: and the whole being kept frequently stirring in a vessel which has formerly held vinegar, or set in a warm place full of the steams of the same, will begin to ferment anew, and conceive heat, and will grow sour by degrees, and soon after turn into vinegar.

The remote subjects of acetous fermentation are the same with those of vinous; but the immediate subjects of it are all kinds of vegetable juices, after they have once undergone that fermentation which reduces them to wine; for it is absolutely impossible to make vinegar of must, the crude juice of grapes, or other ripe fruits, without the previous assistance of vinous fermentation.

The proper ferments for this operation, by which vinegar is prepared, are, 1. The fæces of all acid wines. 2. The lees of vinegar. 3. Pulverized tartar; especially that of Rhenish wine, or the cream or crystals of it. 4. Vinegar itself. 5. A wooden vessel well drenched with vinegar, or one that has long been employed to contain it. 6. Wine that has often been mixed with its own fæces. 7. The twigs of vines, and the stalks of grapes, currants, cherries, or other vegetables of an acid austere taste. 8. Bakers' leaven, after it is turned acid. 9. All manner of ferments, compounded of those already mentioned.

Vinegar is no production of nature, but a mere creature of art: for verjuice, the juices of citrons, lemons, and the like native acids, are improperly said to be *natural vinegars*; because, when distilled, they afford nothing but vapid water; whereas it is the property of vinegar to yield an acid spirit by distillation.

The wine which is generally converted into vinegar, and which for its cheapness is commonly employed for this purpose, is such as has already become sour; although the better and the more spirituous the wine, and also the more of the vinous spirit that can be retained in the vinegar, the better and stronger it will be. Becher says, in his "*Physica Subterranea*," that having digested wine in order to convert it into vinegar, in a bottle hermetically sealed, he found, that although a longer than the ordinary time was required, the vinegar produced was much stronger than when free air is admitted. Mr. Cartheuser also affirms, that the strength of vinegar may be much increased by adding some aqua vitæ to the wine, before it is exposed to the acetous fermentation. Nothing more seems requisite in the preparation of good vinegar than to employ good wine, and to conduct the fermentation in the most advantageous method; the principal part of the operation being performed by nature.

VINEGAR in France, Method of making. The French use a method of making vinegar different from that above described. They take two very large oaken vessels, the larger the better, open at the top; in each of which they place a wooden grate, within a foot of the bottom: upon these grates they first lay twigs, or cuttings of vines, and afterwards the stalks of the clusters of grapes, without the grapes themselves, or their stones, called the *rape*, till the whole pile reaches within a foot of the brim of the vessels; then they fill one of these vessels with wine to the very top, and half fill the other; and with liquor drawn out of the full vessel, they fill up that which was only half full before; daily repeating the same operation, and pouring the liquor back from one vessel to the other; so that each of them is full and half full by turns.

When this process has been continued for two or three days, a degree of heat will arise in the vessel which is then but half full, and will increase for several days successively, without any appearance of the like in the vessel which happens to be full during those days; the liquor of which will still remain cool: and as soon as the heat ceases in the vessel that is half full, the vinegar is prepared; which, in the summer, happens on the fourteenth or fifteenth day from the beginning; but, in the winter, the fermentation proceeds much slower; so that they are often obliged to forward it by artificial warmth, or the use of stoves.

When the weather is exceedingly hot, the liquor ought to be poured off from the full vessel into the other twice a day; otherwise the liquor would be over-heated, and the fermentation would prove too strong; whence the spirituous parts would fly away, and leave a vapid wine, instead of vinegar, behind.

The full vessel is always to be left open at top; but the mouth of the other must be closed with a cover of wood, in order the better to keep down and fix the spirit in the body of the liquor; for, otherwise, it might easily fly off in the heat of fermentation. The vessel that is only half full seems to grow hot, rather than the other, because it contains a much greater quantity of the vine-twigs and stalks than that, in proportion to the liquor; above which the pile rising to a considerable height, conceives heat the more, and so conveys it to the wine below. Boerhaave's *Elem. of Chemistry*, part iii. p. 143, &c. *Phil. Trans.* vol. ii. p. 657.

There is another method, by which a very good vinegar is commonly made at Paris from the lees of wine. A quantity of wine-lees is put into a large tun, and worked up with wine sufficient to render it very fluid. This is then put into cloth sacks, which are arranged in a large

iron-bound wooden vat, the heavy cover of which is laid over them, and serves as a press, that is gradually screwed down till all the liquor is pressed out. The wine, thus loaded with the extractive and tartareous matter of the lees, is distributed in large casks set upright, through the heading of which a hole is cut, which is constantly left open. In summer these casks are simply set in the sun; but in winter they are arranged in a stoved room. The fermentation comes on in a day or two, and when it has got to its height, so much heat is excited, that sometimes the hand can hardly be borne in it. In this case, it must be checked by a cooler air, and by adding some fresh wine to the casks; and, indeed, it is in a due regulation of the heat that most of the practical skill of the maker consists. The process goes on in this way till the whole of the wine is thoroughly acidified, which requires about a fortnight in summer and a month in winter; after which the new vinegar is put into barrels, at the bottom of which are laid a good many chips of beech wood. Here it remains for about a fortnight, during which time it clarifies, and the clear part is then drawn off and kept in well-closed casks. These beech chips may be used over and over again for several years.

The natural colour of good wine-vinegar is a very pale red, but a higher colour is given, if desired, by the addition of elder-berries.

There are several slight variations in the mode of making wine-vinegar, but which need not be detailed. They all consist in exciting a fresh fermentation in wine, and keeping it up in a moderate degree till acetification is complete. Many refuse parts of the vine are of use for this purpose, such as the husks, the four succulent twigs, the marc or cake left in the wine-press, and the like; and after they have once served, they are still more valuable, as the acid which they naturally contain, or which is evolved by them, is more readily produced.

Wine may also be converted to good vinegar without these additions, simply by adding wine, especially when on the fret, to vinegar already made, and exposing it to a proper heat. In this way many manufacturers proceed, keeping their casks always full, by taking out of them at intervals about a third or fourth part, replenishing them with wine, and again bringing the contents to the state of vinegar.

In this country vinegar is chiefly made from malt. The following is the usual process in London. A mash of malt and hot water is made, which, after infusion for an hour and a half, is conveyed into a cooler a few inches deep, and thence, when sufficiently cooled, into large and deep fermenting tuns, where it is mixed with yeast, and kept in fermentation for four or five days. The liquor (which is now a strong ale without hops) is then distributed into smaller barrels, set close together in a stoved chamber, and a moderate heat is kept up for about six weeks, during which the fermentation goes on equally and uniformly till the whole is soured. This is then emptied into common barrels, which are set in rows (often of many hundreds) in a field in the open air, the bung-hole being just covered with a tile to keep off the wet, but to allow a free admission of air. Here the liquor remains for four or five months, according to the heat of the weather, a gentle fermentation being kept up, till it becomes perfect vinegar. This is finished in the following way. Large tuns are employed, with a false bottom, on which is put a quantity of the refuse of raisins or other fruit left by the makers of raisin and other home-made wines, called technically *rape*. These rape-tuns are worked by pairs; one of them is quite filled with the vinegar from the barrels, and the other only three-quarters full, so that the

fermentation is excited more easily in the latter than the former, and every day a portion of the vinegar is laded from one to the other, till the whole is completely finished and fit for sale.

Vinegar, as well as fruit-wines, is often made in small quantity for domestic uses, and the process is by no means difficult. The materials may be either brown sugar and water alone, or sugar with raisins, currants, and especially ripe gooseberries. These should be mixed in the proportions which would give a strong wine, put into a small barrel, which it should fill about three-fourths, and the bung-hole very loosely stopped. Some yeast, or, what is better, a toast soaked in yeast, should be put in, and the barrel set in the sun in summer, or a little way from a fire in winter, and the fermentation will soon begin. This should be kept up constant, but very moderate, till the taste and smell indicate that the vinegar is complete. It should be poured off clear and bottled carefully, and it will keep much better if it is boiled for a minute, cooled and strained before bottling.

In both the vinous and acetous fermentations, an intestine motion, a swelling, a hissing noise, and an ebullition, may be perceived; but the heat produced by the former is scarcely sensible, whereas that produced by the latter is very considerable. Moreover, the vapour which exhales from vinegar, during fermentation, is not noxious, like that of fermenting wine: on the contrary, as the acid of vinegar disengages itself, it seems to acquire more power to bind and retain the inflammable principle, which is the truly dangerous part of these vapours. Besides, vinegar does not deposit tartar as wine does, even though it has been made with wine that had not deposited its tartar; but the sediment of vinegar is a viscid, oily, and very putrescent matter; which is used to cover the grape-stalks that are employed in the making of vinegar, in order to promote the fermentation. The acid of the grape-stalks, which are washed clean and preserved to promote the fermentation of more vinegar, acts powerfully as a leaven or ferment. The casks which have been used are also to be cleansed from the viscid matter just mentioned, and kept for the same use, as they are fitter for the purpose than new casks. When the acetous fermentation is finished, the nature and character of the liquor that has undergone it are totally changed. The taste and smell of wine are partly spirituous and partly acid; though in good wine the latter is scarcely perceptible: the taste and smell of vinegar are also acid and spirituous; but the former quality prevails so much, as almost totally to conceal the latter. The properties of wine and vinegar prove, that the acetous fermentation unfolds in a very singular manner the acid parts of wine, and intimately combines them with the inflammable spirit; so that by changing wine into vinegar, the ardent spirit is no longer perceptible, so that it cannot affect the head and intoxicate; and if it be distilled, the first liquor that rises with a heat less than that of boiling water is not an ardent spirit, as when wine is distilled, unless the vinegar be too new, and the acetous fermentation has not been completely finished; but when old vinegar is distilled, the liquor that first rises is a slightly acid phlegm, which contains the most volatile, the most odoriferous, and the most spirituous part of the vinegar.

When vinegar has run a little beyond the acetous state, and begun to enter on the putrefactive, the putrefaction may be stopped by quenching a red-hot iron in the liquor; and the acid, which has been lost, may in some measure be restored, by the addition of a little spirit of wine, rye-bread, mustard-seed, &c. The putrefaction of vinegar may also be prevented, by racking it off from the feculencies, and keeping

it in a close-stopped vessel, in a cool place. However, such as has once suffered a considerable heat, cannot long be preserved from corruption.

In England, the excise laws relating to vinegar are as follow:

Every maker of vinegar for sale shall take out a licence, for which he shall pay 10*l.*; and shall renew the same annually ten days at least before the end of the year; on pain of 50*l.* 43 Geo. III. c. 69. Sched. (A.) 24 Geo. III. c. 41.

But persons in partnership need only take out one licence for one house.

By 43 Geo. III. c. 68. for all vinegar or verjuice imported, a certain duty shall be paid *per* ton (quantity 252 gallons).

By 43 Geo. III. c. 69. Sched. (A.) for every barrel of vinegar, vinegar beer, or liquors preparing for vinegar, which shall be brewed or made in Great Britain for sale, shall be paid by the maker a certain other duty.

And upon every hoghead of verjuice which shall be made in Great Britain for sale, shall be paid by the maker a certain duty.

And by 49 Geo. III. c. 98. a duty is imposed in lieu of all former duties of customs.

By 10 & 11 W. c. 21. thirty-four quarts shall be accounted a gallon of vinegar, according to the standard ale quart.

Every vinegar-maker shall make entry with the officer of excise of the house or place where he intends to carry on the business; and whether he intends to make vinegar from malt or corn, or molasses or sugar, or from any and what other materials. 26 Geo. III. c. 73.

Such officer may at all times by day and night (but if in the night, in the presence of a constable), enter into any places used by such persons, and take an account of such liquors therein, and shall make a report thereof in writing to the commissioners, leaving a true copy thereof under his hand, with such maker, if demanded, in writing, under the penalty of 10*l.* 7 & 8 W. c. 30. 12 Geo. c. 28. 12 Ch. c. 24.

By 10 & 11 W. c. 21. no vinegar-maker shall receive into his custody any liquors for making vinegar, nor deliver out any vinegar in casks, or by the gallon, without notice first given to the officer, unless from Sept. 29, to Mar. 25, yearly, between seven in the morning and five in the evening, and from Mar. 25, to Sept. 29, between five in the morning and seven in the evening; on pain of 50*l.*

On receiving such liquors into his custody, he shall shew the same to the gauger before he mixes them with any other liquors, rape, or other materials; on pain of 20*l.*

If any vinegar-maker shall, without giving notice at the next excise-office, or to one of the commissioners, use any store-house, warehouse, cellar, or other place, for making or keeping any vinegar beer, or liquor preparing for vinegar, he shall forfeit 5*l.*

If any maker of vinegar for sale shall conceal any vinegar, or liquor preparing for vinegar, from the view of the gauger, he shall for every barrel forfeit 40*s.* 7 & 8 W. c. 30.

If such maker shall, on demand made by such gauger in the day-time (or if by night, in the presence of a constable), refuse to permit him to enter his house, store-house, or other place used by him, and to take an account of the said liquors, he shall forfeit 15*l.*

No person carrying on the trade of a vinegar-maker from molasses or sugar, or other materials, (except malt or corn,) shall carry on (either alone or in partnership) the trade of a

distiller or rectifier of spirits in the same premises, or within two miles thereof; and all entries made by such person shall be void. 26 Geo. III. c. 73.

All stale beer, returns of beer or ale, cyder, verjuice, or any other liquor proper to be made into vinegar, which shall be found in the possession of any common vinegar-maker, except such as are to be drunk in his family, and which shall be kept separate for that purpose, shall be deemed vinegar or liquors preparing for vinegar. 10 & 11 W. c. 21.

Every such vinegar-maker shall make entry once a month at the next excise-office of all liquors made within that month, and also within a month after such entry, shall clear off the duties, on pain of double duty. 12 Ch. II. c. 24.

All penalties and forfeitures are to be recovered, levied, and mitigated as by the excise laws. 43 Geo. III. c. 69.

VINEGAR, *Chemical Properties of the pure Acid of the different Kinds of.* See ACETOUS Acid.

The quantity of fixt alkaline salt which vinegar is capable of saturating, is one of the surest criterions of its strength. The best of the German vinegars, according to Stahl, saturate little more than $\frac{1}{10}$ th of their own weight; the French vinegars, examined by Geoffroy, above $\frac{1}{10}$ th; and some of them no less than $\frac{1}{12}$ th; the common distilled vinegar of our shops about $\frac{1}{10}$ th. By congelation, and distillation from alkalies, and from some metallic bodies, particularly copper, the acid may be so far concentrated as to saturate nearly equal its own weight. The best way of judging of the saturation, according to Dr. Lewis, is by trying the liquor from time to time with certain coloured vegetable juices, or on paper stained with them. For this purpose, a thick writing paper may be stained pale blue on one side with the blue preparation of archil, commonly called lacmus; and pale red on the other side, by a mixture of the same infusion with so much diluted spirit of salt as is just sufficient to redden it. If a small slip of this paper be dipped occasionally into the liquor to be tried, or a drop of the liquor be applied on both sides of the paper, the red side turns blue as long as any of the alkali remains unsaturated; the blue side turns red, when the acid begins to prevail; and no change at all is produced, when the saturation is complete. Where lacmus cannot be procured, the paper may be coloured with the juices of violets, iris, cyanus, &c. or with the blue juice pressed out from scrapings of the cortical part of common radish roots; with which it is sufficient to stain the paper on one side; this one colour discovering both acidity and alkalescence, the former changing it red, and the latter green.

The acetous acid differs essentially from all the others: from the native vegetable acid, in subtility and volatility; not being obtainable in the form of a concrete salt, which most, perhaps all, of the native ones are, and rising in distillation with a moderate heat, which very few of the native ones have been found to do: from the mineral acids, in its habitude to different bodies, and the nature of the compounds which it forms with them, being much weaker than the mineral acids: thus, whatever alkaline, earthy, or metallic substance the acetous acid be combined with, the addition of any mineral acid will disjoin them, the mineral taking the place of the acetous; neutral salts, composed of the acetous acid and fixed alkalies, dissolve totally and plentifully in rectified spirit of wine, whilst those composed of the same alkalies and mineral acids are not at all soluble in that menstruum: in this property, the acetous acid differs also from most, perhaps from all, of the acids of its own kingdom; and from all acids in general, in its peculiar odour.

The acid of vinegar dissolves all substances upon which other acids can act, and forms with them neutral salts, all which may be called acetous salts. With calcareous earth it forms salts, which in crystallizing shoot into silky ramifications and vegetations: these salts are named, from their earthy bases, salt of chalk, salt of crabs' eyes, &c. (See ACETITE of Lime, &c.) The solubility of calcareous earth in this acid, and its precipitability by that of vitriol, afford a ready method of discovering the sophistication of vinegar, said to be sometimes practised, with vitriolic acid. If a saturated solution of any calcareous earth, as chalk, made in strong vinegar, be added to such as is suspected of containing vitriolic acid, no change will ensue, if the vinegar was pure; but if it contained even a minute portion of that acid, the mixture will immediately become milky, and, on standing for a little while, deposit a milky sediment: if the calcareous solution be gradually dropt in, so long as it produces any milkiness or cloudiness, all the vitriolic acid will be absorbed by the chalk; and as this new compound is very sparingly dissoluble, nearly the whole of it will precipitate, so as to leave the vinegar almost pure. Its adulteration with vitriolic or sulphuric acid may also be detected by a solution of nitrate of barytes, which forms a white precipitate, when dropped into the suspected vinegar, insoluble in nitric acid, after having been exposed to a strong heat. With fixed vegetable alkali the acid of vinegar forms a very pungent and very deliquescent salt, called *Regenerated Tartar*, or *TERRA foliata tartari*; which see. (See also ACETITE of Potash.) With fixed mineral alkali it forms a neutral crystallizable salt. With volatile alkali it forms an acetous ammoniacal salt, called *Spirit of Mindererus*. See ACETITE of Ammonia.

Vinegar dissolves, among metallic bodies, zinc and iron; and the rest with difficulty, if at all. (See ACETOUS Acid.) United with copper, it forms a verdigris and crystals of Venus. With lead it forms cerusse, and salt or sugar of lead; dissolving it more easily when reduced to a calx than in its metallic state; boiled even with the glass of lead, or in the common glazed earthen vessels, in the glazing of which this metal is a principal ingredient, it extracts so much as to become strongly tainted with the pernicious qualities of the lead. Gold, platina, silver, and quicksilver, are not affected by vinegar in their metallic state; the two first have not been observed in any state to be affected by it. Silver precipitated from the nitrous acid, and thoroughlyedulcorated with water, and mercury treated in the same manner, or changed by fire into a red powder, slowly and sparingly dissolve in it. Of the affinities of this acid to different metals, or its forsaking one to unite with another, few experiments have been made. Dr. Lewis observes, that it deposits lead and copper upon adding iron. (See TABLES of AFFINITY.) It dissolves the vegetable inspissated juices, and several of the gummy resins, and extracts the virtues of sundry plants in tolerable perfection, superadding at the same time a virtue of a different kind. However, it excellently assists and coincides with some drugs, as garlic, squills, and ammoniacum; and in many cases, where this acid is principally to be depended upon, it may be advantageously impregnated with the flavour of certain vegetables. Vinegar very much concentrated, as the rectified spirit of Venus, or radical vinegar, being distilled with equal parts of highly rectified spirit of wine, furnishes a liquor which has all the essential characters of ether, and is called *acetous ether*. It was discovered by the count de Lauraguais. (See Hist. Acad. Scienc. Par. 1759.) It mingles equally with blood and its serum, and with most of the fluids of animals; not thickening or coagulating them, like the acids

of the mineral kingdom, but tending rather, as Boerhaave justly observes, to attenuate and resolve coagulations. It is likewise, when taken internally, less stimulating than the mineral acids, and less disposed to affect the kidneys. Professor Cullen observes, that it is less liable to undergo changes in the first passages than the native vegetable acids, which have yet to go through the process of fermentation. The use of vinegar as a condiment, and as an antiseptic for pickling and preserving dead animal and vegetable matter, is well known.

VINEGAR, Medicinal Properties of. This mild, unctuous acid is a medicine of great use in the different kinds of inflammatory and putrid distempers, both internal and external. Nothing is more extolled in many cases of putrefaction, and as an antidote against venomous bites, by Dioscorides and Hippocrates, than oxycrate; and vinegar, when applied to sores in animal bodies, is known to stimulate and resist putrefaction. When weak, it possesses the virtues of water; when strong, its effects approach to those of salts and acid spirit. *Med. Ess. Edinb. vol. v. art. 24.*

It is one of the most certain antiphlogistics and sudorifics in high fevers, and one of the best preservatives against pestilential and other putrid contagious contagions. Accordingly Boerhaave informs us, that Franciscus de la Boe Sylvius visited his patients in the plague with safety, by drinking first an ounce or two of vinegar. And it is now a common practice to wash and sprinkle the rooms of hospitals, the decks of ships, &c. with vinegar, in order to purify the air. Dr. Hales (*Ventilators*, part i. p. 46.) recommends dipping many cloths in vinegar, and hanging them up in all proper vacancies between the decks of ships, and in the chambers of sick persons, by which great quantities of vinegar would intermix and float in the air; and he found by an experiment, mentioned in his *Statical Essays*, vol. i. p. 266, that an air which passes through such cloths, could be breathed to and fro as long again, as the like quantity of air which was not impregnated with vinegar. Fainting, vomiting, lethargic and hysterical paroxysms, are likewise frequently relieved by vinegar, applied to the mouth and nose, or received into the stomach. Lethargic persons are often found to be excited more effectually by vinegar blown into the nose, than by the far more pungent volatile spirits. Boerhaave observes, that this acid counteracts, in a peculiar manner, the effects of spirituous liquors. The daily use of vinegar with food is salutary in hot, bilious dispositions, and where there is a tendency to inflammation or putrefaction. It is prejudicial to children, to aged, hysterical, and hypochondriacal persons; in cold, pale, phlegmatic habits, where the vessels are lax, the circulation languid, and the power of digestion weak. It tends in all cases, if used freely, to prevent corpulence. Hoffman suspects that it produces this effect by impeding the formation of chyle, or destroying the union of the unctuous and serous fluids of which chyle is composed; an effect common to all acids, as appears from their coagulating milk and artificial emulsions. Dr. Lewis observes, that he has known great corpulence reduced by the liberal use of vinegar, but not with impunity: diseases succeeding, which eluded the power of medicines, and proved at length fatal.

Combinations of vinegar with different earthy bodies, differ in virtue according to the nature of the earth. A solution of the aluminous earth in this acid is strongly styptic; of vegetable earth, or magnesia alba, bitterish and gently purgative: both these solutions are milder, and less ungrateful, than those of the same earths made in the mineral acids; and, though as yet unknown in practice, certainly deserves, as Dr. Lewis says, to be introduced. Solutions

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of different animal and the calcareous mineral earths are bitterish and subaustere, in various degrees, and supposed to act as mild resolvents, subastringents, or diaphoretics. Combinations of vinegar with fixed alkaline salts are useful aperients, diuretics, and cathartics. Dr. Lewis has known two drachms of the alkali, dissolved in as much vinegar as was sufficient to saturate it, occasion ten or twelve copious watery stools, and a plentiful discharge of urine, without griping or fatiguing the patient. Mixtures of alkali and distilled vinegar, evaporated to a dry salt, are kept in the shops; either in a brownish oily state, as obtained by simple evaporation, or purified to perfect whiteness, by gentle fusion or solution in water. These preparations are given in doses of ten or twenty grains as mild aperients, and to a drachm or two as purgatives and diuretics. See **TARTAR, Regenerated**, **SAL Diureticus**, **TERRA Foliated**, and **ARCANUM Tartari**.

Combinations of vinegar with volatile alkaline salts, commonly made with distilled vinegar, added gradually to the salt, till the effervescence ceases, scarcely yield any solid salt; the saline matter evaporating with the watery fluid, or even before it: on distilling the mixture in a retort, a salt sometimes concretes about the sides of the receiver, but liquefies again as the vessels grow cold. These mixtures, called *Spiritus Mindereri*, have little purgative virtue, but operate powerfully as aperients; by urine, if the patient walks about in the cool air; by perspiration or sweat, if kept warm in bed. They are principally made use of in this last intention, in doses of half an ounce; and, as they act without irritation, they have place in inflammatory cases, where the warm sudorifics, if they fail of exciting a sweat, aggravate the distemper. Vinegar and honey, or oxymel, of the consistence of a syrup, swallowed warm, is very good in many cases of sore throats arising from colds. A very important medicinal virtue has been attributed to vinegar, namely, that of curing the canine madness. See **HYDROPHOBIA**, and **MADNESS from the Bite of enraged Animals**.

M. Buchoz, in a work, entitled "*An historical Treatise of Plants growing in Lorraine, &c.*" affirms, that several successful trials have ascertained the efficacy of vinegar against the ill effects arising from the bite of mad dogs, when it is given in the quantity of a pound each day, divided into three doses; one to be taken in the morning, another at noon, and a third in the evening. Upon the whole we shall here observe, that vinegar, taken into the stomach, acts as a refrigerant, promotes diaphoresis and the discharge of urine; and is a powerful antinarcotic: externally its action on the living fibre is moderately stimulant and astringent. In inflammatory fevers it may be used to acidulate the ordinary beverage. It is given as a remedy in putrid diseases and scurvy; and is the most easily procured, and the best means of counteracting the fatal effects of overdoses of opium, and other narcotic poisons; for which purpose it should be administered in table spoonfuls, frequently repeated, after the stomach has been emptied by a proper emetic. It is employed as a glyster in obstinate costiveness; and externally, in the form of fomentation, or of lotion, is applied in burns, bruises, sprains, and chronic ophthalmia; and diluted with water, it is the best lotion for clearing the eye of small particles of lime, when they adhere to any part of the ball, or the lids. Its vapour is inhaled in putrid fore-throat; and diffused through sick rooms, with the view of neutralizing pestilential effluvia; but as a fumigation it has little efficacy. The dose of vinegar is $\text{f}\text{3j}$ to $\text{f}\text{3ij}$; and the quantity given in clysters $\text{f}\text{3j}$ to $\text{f}\text{3ij}$. See on the subject of this article, Boerhaave's *Elem. Chem.* by Dallowe, part iii. p. 146, &c. Neumann's *Chem.* by Lewis, p. 458, &c.

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Dict. Chem. Lewis's: Mat. Med. Thomson's Lond. Disp. See also ACETIC Acid, ACETITE, ACETOUS Acid, and ACETUM.

VINEGAR, in *Rural Economy*, is an acid or cooling liquid that may be made use of with considerable benefit in different sorts of field labour, in mixture with water or other fluids, as quenching thirst very effectually, without stimulating or increasing the heat of the body too greatly. It has been stated, on the authority of a manuscript paper found in possession of sir William Pulteney on the use of vinegar, by the writer of the Corrected Report of the Agriculture of the County of Middlesex, that during the first American war, the interruption given by our cruisers to the trade of that country, and some other circumstances, prevented the inhabitants of it from procuring proper supplies of molasses for their distilleries, and a distress was experienced, particularly in harvest-time, from the want of rum to mix with water, which was the drink of their labourers. It is commonly known, the writer thinks, that cold water is dangerous, when used by persons heated with labour, or by any severe exercise; and yet it is necessary to supply the waste and exhaustion of perspiration in some mode or other. When rum or wine is added in small quantity to water, it may be used, even if cold, with little danger: it would, however, be safer, it is supposed, if a little warm water were mixed and employed in such cases.

On this account, Dr. Rush, of the same country, after making proper experiments on the subject, recommended in a publication, that instead of rum, which could not then be had, the labourers in harvest should mix a very small proportion of vinegar with the water they made use of as drink. Some years afterwards, in another publication, the same writer mentioned that the practice had been adopted, and had succeeded even beyond his expectations; indeed so much so, that in many places vinegar was still continued to be used, though rum could easily be had. The preference of vinegar to rum is accounted for in this manner: severe labour or exercise excites a degree of fever; and that fever is increased by spirits or fermented liquor of any sort; but vinegar, at the same time that it prevents mischief from drinking cold water during the heat and perspiration occasioned by exercise, allays the fever; and the labourers found themselves more refreshed and less exhausted at night, when vinegar was used instead of rum.

The exact proportion of the vinegar is not known by the writer, but it is supposed that it was not more than about a tea-spoonful to half a pint of water.

The discovery, it is said, was not altogether new, as the Romans used vinegar to mix with water for the drink of their soldiers.

The writer of the above agricultural report adds to this, that M. Denon, a celebrated French draughtsman, who accompanied their army while it was in Upper Egypt, experienced the advantage of vinegar mixed somewhat in this way in that burning climate, which he relates in this manner: "I cooled the heat of my blood with vinegar, which I mixed with water and sugar, and drank of it largely."

Independently of this, however, the same writer states, that the quality of water, which produces the ill effects above described to persons drinking it cold, when under any considerable degree of perspiration, may probably be corrected by the simple addition of skim-milk. The labourers in some districts of this kingdom, it is said, during harvest, make use of no other beverage than milk and water, which is found to allay the fever, and quench the thirst, much more than beer. At the same time, the labourers are

glad when they can get beer or ale, though they confess that they are much sooner thirsty after drinking either, than they are after drinking milk and water, or it would seem than vinegar and water.

As it is necessary to have good and well-kept vinegar in this intention, as well as for some domestic and other purposes, it may be proper to consider the nature of it, and the means of preserving and preventing the decomposition and injury of it in any way. Where good vinegar is wanted, wines of good quality are necessary, as the best kinds of it are those that have been made from generous wines. The more spirituous the wine is, and the more of this vinous spirit that can be retained in the vinegar, of course the better and stronger it will be, and consequently the more fit for the above uses. In regard to the means of its preservation, they principally consist in defending it well against the action or influence of the external air, by keeping it in proper vessels, well closed, and placed in cool situations. Its alterations and injuries may likewise be further retarded, where necessary, by depriving it of a portion of the water which it contains; for which purpose, nothing more is wanted than to just let it boil for an instant; but the vessels which are employed in this kind of business should obviously not be made of copper. The process too, which has been proposed by some with a similar intention, is quite simple; it consists in filling with this acid glass vessels of a proper kind, which are to be then placed in boilers full of water; the water being in this case made to boil for a full quarter of an hour, after which the vinegar in the vessels is taken out, when it may be kept for several years without undergoing any alteration or decomposition. Distillation, too, has been advised as a means of preserving vinegar; but besides the circumstance of its being a tedious and difficult process, it is apt to deprive the acid of the agreeable smell and taste which are peculiar to it in its natural state, and which is always desirable, but more especially when for use in the above intention. And the same is the case with vinegar that has been concentrated by freezing. The acid by this simple operation becomes much stronger, and capable of being kept for a much greater length of time; but it acquires something of a burnt smell and taste, which render it unfit for being employed for many domestic purposes, as well as that above stated.

There is another manner of accomplishing this business by a saline substance, which is that of sea-salt, or muriate of soda, which is advised by some to be added to vinegar, as being able to preserve it, and which succeeds well enough in some cases, though it is not without its inconveniences; for the vinegars that contain this material grow turbid, and at length lose their primitive qualities. But though it may not succeed quite so perfectly as might be wished, it may still be employed in certain cases with advantage, especially if the quantity of salt that is necessary to be added to the vinegar be not in too large a proportion.

What respects the signs by which vinegar may be known to be good, adulterated, or spoiled, deserve considerable attention, as nothing is more common than to meet with vinegars that are of bad quality. Two causes principally contribute to their being in that state: the first of which is, that they have been manufactured or prepared with weak wines, or such as are already in a spoiled condition; the second, that they have been mixed with acrid substances, such as pimento and others; or that mineral acids, such as the sulphuric or muriatic, have been added to them. Nothing is, however, more easy than to detect such frauds and impositions, it being sufficient for the purpose to merely saturate a given quantity of potash with the vinegar which is

suspected of adulteration, and to compare the quantity of vinegar that has been obliged to be employed before a complete saturation could be obtained, with that consumed in a similar trial made with vinegar, the good quality of which is well known; and by evaporating or reducing the substance of the solution nearly to dryness afterwards, the nature of the material employed may be ascertained. And as to the acrid vegetable substances that may have been mixed with it, they may be readily recognized by their taste, which will be altogether different from that of the vinegar, and which will become the more perceptible, the more the acid has been concentrated or reduced by evaporation, or any other means.

It may be noticed in general, that vinegar which has not been adulterated, or which has not been spoiled by an incipient decomposition, is readily and easily known by its penetrating acid taste, its transparency, and its agreeable smell, which becomes still more developed if some of the vinegar be rubbed between the hands, or in any other way.

In some of these modes, vinegar that is fit for use in the above intention, and for other purposes, may be readily known.

Vinegar is frequently also of much utility and advantage as an application in different cases of bruises and slight swellings, arising from blows and other accidents among different kinds of live-stock or domestic animals.

VINEGAR of *Antimony*, is an acid spirit, best made by distillation from the ore of antimony. See ANTIMONY.

Its use is recommended in continued and malignant fevers.

VINEGAR, *Aromatic*, of the Edinb. Ph., is prepared by taking of rosemary tops dried, and sage leaves dried, of each 4 oz.; lavender flowers dried, 2 oz.; cloves bruised, 2 dr.; and distilled vinegar, 8 lbs.: macerating these ingredients for seven days, and filtering the expressed liquor through paper. The odour of this liquid, which is a solution of the volatile oils of the substance employed in vinegar, is pleasant, pungent, and aromatic; and it is a grateful perfume in sick rooms, but cannot be regarded as a prophylactic from fever, or other contagions.

The aromatic spirit of vinegar, originally invented and successively improved by the late ingenious and respectable Mr. Henry of Manchester, is composed of highly concentrated vinegar, joined with the most pleasant aromatic and efficacious antiseptics, and may be kept unimpaired for any length of time, and in any climate. Its fragrant odour adapts it for affording relief in head-aches, faintings, &c. and renders it peculiarly grateful and refreshing in crowded rooms, places of public resort, and the apartments of the sick. It is also said to counteract the infection of contagious diseases.

VINEGAR, *Distilled*, is the spirituous acid of vinegar obtained by distillation. The process of distilling vinegar is very simple. A quantity of good ordinary vinegar is put into a large cucurbit or still, which ought to be made of stone-ware, and not of metal, as the acid of vinegar is capable of acting upon most metals. This cucurbit is sunk in a deep furnace, so that five or six fingers' breadth only near its neck appear. The neck is to be carefully luted with clay all round the furnace, that the capital may not be heated too much. A capital and a glass receiver are then to be fitted, and the distillation is to be begun with a very gentle heat. The acid spirituous liquor passes by drops into the receiver. This liquor is white, transparent, penetrating, somewhat empyreumatic, and disengaged from an acid, but not spirituous substance, and also from an extractive sapo-

naceous matter, both which are contained in ordinary vinegar. These latter substances remain in the still with the colouring matter, and form together an extremely acid extract of vinegar. This residuum contains also some tartar, and by incineration yields much fixed alkali, as all matters belonging to vines, grapes, and wine do.

The thicker vinegar is, the less fit it proves for distillation, as there is always the greater danger of an empyreuma, or burnt smell, which would spoil the whole process, and as it usually in this case comes over oleaginous. And the purest white salt of tartar, saturated with this distilled vinegar, being afterwards ignited, turns black, and yields a smell extremely like that of crude tartar in the calcination. Shaw's Chemical Essays.

On the other hand, the more the vinegar is diluted immediately before distillation, the less danger there is of burning; and if the thick remaining mass, when the thinner part is distilled from it, be again diluted with water, it may, by a second distillation, be brought to afford an acetous substance; though this latter be by no means comparable to this former volatile part. This Vignani justly suspects to be a circumstance known but to very few. And even when the vinegar is distilled with the utmost labour and care, it still has this effect in a higher degree, and contains an immense quantity of phlegm, in proportion to its acid salt.

In this case, the method of condensation by freezing is of the utmost service; first of all separating the more aqueous part, and in the next place that which is somewhat acetous, though not comparable to what remains behind; so that, by this means, a most concentrated and subtle spirituous distilled vinegar may be produced, viz. by freezing the whole parcel of distilled phlegm and distilled vinegar together, a thing of great moment to the curious in the *chemia subtilior*, and particularly to those who understand Hollandus. And when the vinegar is froze without distillation, by this means you have a noble rob, or a rich concentrated vinegar, freed from its distilling aqueous and useless part. Vignani, Medull. Chem.

The Lond. Ph. directs the acetic acid to be distilled from a gallon of vinegar in a glass retort, placed in a sand-bath, into a glass receiver kept cool; the first pint to be thrown away, and the six succeeding pints which are distilled to be preserved. The distilled acetous acid of the Edinb. Ph. is prepared by distilling 8 lbs. of the acetous acid in glass vessels, with a gentle heat, rejecting the 2 lbs. which first came over, as being too watery; and the 4 lbs. that follow will be the distilled acetous acid: the residue is a stronger acid, but too much burnt. The distilled vinegar of the Dub. Ph. is obtained by taking of wine vinegar ten pints, and distilling with a gentle heat six pints: the distillation is to be performed in a glass vessel, and the first pint which comes over rejected. The specific gravity of this acid is to that of water as 1006 or 10095 to 1000. (See ACETOUS Acid.) Darracq has ascertained (Annales de Chimie, xli. 264.) that distilled vinegar differs from acetic acid, by containing some uncombined mucilage and extractive matter, but that the acids are otherwise the same. To this extractive it is owing, that when distilled vinegar is boiled with potash, the solution has a deep reddish-brown colour, and during evaporation carbonaceous matter is deposited. Sulphuric acid is detected by a precipitate being produced on the addition of a solution of acetate of barytes; lead, by a solution of sulphuretted hydrogen, forming a dark-coloured precipitate; and copper, by its assuming a blue colour, when supersaturated with ammonia. The medical properties and uses of distilled vinegar are the same with those of common vinegar; but, being purer, and less

liable to spontaneous decomposition, it is fitter for pharmaceutical purposes. Thomson's Disp.

VINEGAR, *Concentrated*. See CONCENTRATION.

VINEGAR of *Lead*, is a liquor formed by digesting cerusse or litharge, with a sufficient quantity to dissolve it perfectly. This is called the *acetum lithargyrites*, and is prepared by digesting four ounces of litharge about three days in a sand heat, with a pint of strong vinegar, now and then shaking the vessel. The liquor, filtered, will receive a strong impregnation from the litharge, and will be found to have dissolved about one-tenth of it. When a saturated solution is required, the cerusse is preferred to the litharge. This vinegar is of the same nature with solutions of saccharum saturni, and when diluted with a large quantity of water, it abates external inflammations, the itching and other uneasinesses in cancerous ulcers; and before Mr. Goulard's practice, it was used for bathing inflammations in scirrhus tumours, to prevent their becoming cancerous. Inflammations and inflammatory tumours, in general, are dispersed by it. Dr. William Saunders has observed, that the acetum lithargyrites, or Goulard's extract, is not the same in its operation and powers as the saccharum saturni, as medical practitioners have generally supposed. In the preparation of the former, the acid is fully saturated with lead; but in that of the latter, the acid is in a much greater proportion to the lead. The former, when diluted by the purest distilled water, gives out a copious precipitation, which he finds, by experiment, to be cerusse. The latter remains dissolved in distilled water, and is, therefore, applied topically in a state more immediately active, both on account of its greater proportion of acid, and its preserving its solubility under high degrees of dilution. He has also found by experiment, that, by adding a very small proportion of distilled vinegar to the aqua saturnina of Goulard, the white precipitate is redissolved, and that the solution procured in this manner is more active, but less adapted to remove inflammation, and abate irritation, as a sedative, than the aqua saturnina itself. Dr. Saunders, however, is perfectly convinced that no degree of dilution of saccharum saturni will answer the many valuable purposes obtained from the use of the acetum lithargyrites. Water alone, in the case of the aqua saturnina, proves a precipitant of lead, by attracting the acid, and reducing the preparation to a state of cerusse, an intermediate state between lead and the saccharum saturni; so that cerusse diffused in water more nearly resembles the aqua saturnina of Goulard, than a solution of the saccharum saturni does. The saccharum saturni may be considered as an union of cerusse with vinegar; whereas Goulard's acetum lithargyrites is an union of lead with vinegar. See Percival's Phil. Med. and Exp. Ess. 1776. Append. p. 323, &c. See also LEAD.

VINEGAR of *Meadow Saffron*, *Acetum Colchici*, is ordered by the London College to be prepared by taking of the meadow saffron root (bulb) sliced, 1 oz.; of acetic acid, a pint; and of proof-spirit, a fluid-ounce; macerating the root with the vinegar in a covered glass vessel for twenty-four hours, then expressing, and setting the liquor aside, that the feculencies may subside, and adding the spirit to the clear liquor. This is given as a diuretic in ascites and hydrothorax, but is less to be depended on than the squill. The dose is from ℥ss to ℥j, united with honey, or any bland fluid. See COLCHICUM and MEADOW SAFFRON.

VINEGAR, *Portable*, a name given by the chemists to a sort of vinegar-powder, or vinegar in a dry form. It is a preparation of tartar with vinegar, and is made in this manner: Take white tartar, half a pound; let it be carefully washed, then dried and powdered; infuse this powder in the

strongest wine-vinegar; then dry it, and infuse it again, repeating this operation ten times: after this the dry powder is to be kept for use. At any time, a sort of extemporaneous vinegar may be made by dissolving a small quantity of this powder in any proper liquor.

VINEGAR, *Prophylactic*. See ACETUM Prophylacticum.

VINEGAR, *Radical*, is a name given to the acid of vinegar, highly concentrated, by distilling verdigris, or crystals of verdigris, &c. See ACETIC ACID.

M. de Laffone has lately found, that in the process of distilling verdigris for this purpose, a fluid escapes of the nature of those called by the ancient chemists *gas*, and by the moderns *fixed air*; and he also observed, that if the distillation be suspended the moment before the acid concentrated vapours appear under a white form, copperish flowers are obtained: before this period, the radical vinegar contains no copper; it only begins to contain some, when the copperish flowers, carried along by the acid vapours, mix themselves with this vinegar: if it is then rectified by a new distillation, these flowers are no more sublimed, and, therefore, a radical vinegar, exempt from copper, may be extracted from verdigris. The copperish flowers are in a high degree caustic, and may be considered as a violent poison. Hist. Acad. Sc. Par. 1777.

VINEGAR of *Roses*. See ACETUM Rosatum.

VINEGAR of *Squill*. See SQUILL.

VINEGAR, *Eels in*. The common opinion, from the discovery of eels in vinegar, that its sharpness to the taste was occasioned by these animals, caused the accurate Leewenhoeck to attempt a careful examination of it by the microscope.

Some of the strongest and sharpest vinegar, after having been exposed for some hours to the air, and afterwards examined by the microscope, entertains the sight with a number of corpuscles, called the salts of vinegar, which are acute at both extremities, and have many of them in the middle an oblong figure of a brownish colour, and others were altogether clear, pellucid, and bright as crystal. Others of these particles appeared of an oval figure, and some of the half of such a figure, hollowed like a small boat, or the half of a nut-shell. The more perfect figures, pointed at both ends, and pellucid, are so very minute, that some thousands of them are comprehended in a small drop.

These seem to be what affect the tongue with the acid sharpness, when we taste vinegar; and it is very probable, that beside these, minute as they are, there are multitudes of others, equally pointed, and infinitely smaller than these.

If vinegar be placed in an open glass, and suffered to remain some weeks, the surface of it will be found, on examination with good glasses, to be full of the same figures, double-pointed, and very pellucid; and in these, very often, there may be cavities plainly discovered; but examining the liquor a little deeper down, there are found numbers of minute eels; yet these, though minute, are prodigiously larger than the salt particles, and can never be supposed to be the occasion of the sharpness of vinegar to the taste, by any who rightly consider, since it is not all vinegar that contains them; nay, the much greater part of vinegar is wholly without them, and in winter they all die; yet vinegar is not less sharp at that season than in the summer.

Mr. Mentzelius was so lucky as to see these undergo their last metamorphosis, and change into small flies; and though this is a single instance, in regard to the microscopical world of animalcules, yet it is highly probable that the whole race of those, whose appearance in medicated fluids we have been so long puzzled to account for, may, like these, be the worm-state of some winged aerial insect, and have owed

their origin, where we see them, to the eggs of parent flies, too small for our sight. Reaumur, Hist. Inf. vol. iv.

If vinegar be impregnated with crab's-eyes, or any other alkaline substance, which blunts, and in a great measure destroys its acidity, these double-pointed figures are no longer found in it, on a microscopical inspection; but in their places we find others with an oblong quadrangular base,

from which they shoot up into pyramids, and appear like polished diamonds. These are also so very minute, that six thousand of them are computed to be contained in a drop of the liquor, no larger than two corns of barley; and these will be usually found all of the same size, or very nearly so, which is by no means the case with the other sorts of vinegar in its natural state. See *Microscopic* EELS.

Vitriol

VITRIOL, NATIVE, in *Mineralogy*, is a substance of greyish or yellowish-white, apple or verdigris-green, or sky-blue colour; and when decomposed, covered with an ochrey crust. It occurs in mass, disseminated, stalactical, and capillary. Externally it is rough and dull; internally it is more or less shining, with a vitreous or silky structure. Its fracture is generally fine and straight fibrous, sometimes also lamellar and conchoidal. It is soft, brittle, and translucent, and has an acerb metallic flavour. It is more or less soluble in water, and is a mixture in various proportions of the sulphate of iron, copper, and zinc. It is not unfrequently found in caverns and shafts, in argillaceous schistus, and in old mines, especially such as abound in blende and pyrites. Aikin.

Some take the word *vitriolum* to be used *quasi vitri oleum*, because of its shining colour; but Menage rather derives it à *vitreo colore*: the Latins call it *atramentum futorium*; and the Greeks, *chalcanthus*.

It acquires different names, according to the different places where it is dug; and the vitriols of those also differ from each other in denomination and colour; some being *white*, others *blue*, and others *green*.

Roman and Cyprus vitriol, for instance, is blue; and that of Sweden and Germany, commonly called English vitriol, is green; besides which there is also a white kind, called Goslar vitriol.

Vitriol is very commonly called by the manufacturers copperas; accordingly, we constantly hear of green, blue, and white copperas. The constituent parts of the different kinds of vitriols were not understood by the ancients so well as they are at present: they seem to have had an idea, that copper was the basis of them all: hence the Greek term for vitriol, *chalcanthus*, the efflorescence of copper, and the Latin one, *cuperosa* or *cupri rosa*, the flower or efflorescence of copper; from which, says Dr. Watson, the French *couperose*, and our copperas, are evidently derived. See **CABRUSI**.

Some moderns take the *chalcitis*, or *chalcanthum* of the ancients, which they supposed to be a native vitriol, that had acquired, according to their opinion, its full perfection in the entrails of the earth, and which is a kind of mineral stone, of a reddish colour, to be the same with that *chalcanthum* brought from Sweden and Germany; the best of which is of a brownish-red colour, and a vitriolic taste, and dissolves easily in water; and when broken, is of the colour of shining copper. See **VITRIOLIC Minerals**.

The vitriols which nature prepares are never to be met with in commerce; they serve to adorn the cabinets of the curious, but they are neither sufficiently pure for the purposes to which common vitriols are applied, nor are they found in sufficient quantities to answer the demand which is made for them.

VITRIOL, in *Chemistry*, is a term that is now applied to every combination of the acid of sulphur with any metallic substance: three of these combinations, however, are more particularly distinguished, being of great use in various manufactures; viz. *green vitriol* or *sulphate of IRON* (which see), *blue vitriol* or *sulphate of copper* (see **COPPER** and **COPPERAS**), and *white vitriol* or *sulphate of zinc*. (See **ZINC**.) The acid in all these vitriols is the same; the metallic basis of the green vitriol is iron, that of the blue vitriol is copper, and that of the white vitriol, zinc.

According to the analysis of sir Torbern Bergman, (Essays, by Cullen, vol. i. p. 180.) 100 parts of blue vitriol, or vitriolated copper, crystallized, contain 26 of copper, 46 of vitriolic or sulphuric acid, and 28 of water. According to Kirwan, 100 parts contain 30 of real acid, 27 of copper, and 43 of water. The taste is acescent, æruginous, and caustic; it calcines in heat; one part, in a moderate heat, requires nearly four parts of water, but much less of boiling water. Of white vitriol, or vitriolated zinc, 100 parts contain 20 of zinc, 40 of vitriolic acid, and 40 of water. According to Kirwan, 100 parts contain 22 of acid, 20 of zinc, and 58 of water. In a moderate heat, one part requires more than two of water, but much less of boiling water. Its taste is acescent, astringent, and caustic. Of green vitriol, or vitriolated iron, 100 parts contain 23 of iron, 39 of vitriolic acid, and 38 of water. According to Mr. Kirwan, 100 parts of it, recently crystallized, contain 20 of real acid, 25 of iron, and 55 of water. In moderate heat, one part requires six of water, but three-fourths of boiling water. In heat it splits into a yellow powder; in the fire, into a ferruginous powder. The taste is acescent, styptic, and caustic.

Green vitriol is often met with native in our coal-mines. From an old cannel coal-pit, near Wigan in Lancashire, Dr. Watson procured a considerable quantity of it, very well crystallized; and Dr. Rutty has observed, that the vitriolic water at Haigh, in Lancashire, is the strongest in Britain, yielding 1920 grains of vitriol from a gallon of water. See **VITRIOLIC Waters**.

The *green vitriol*, or sulphate of iron, commonly called English vitriol or copperas, and the Roman vitriol of the Italian writers, is prepared at Deptford, near London, and many other places, from martial pyrites, which is a native sulphuret of iron, and is found in abundance on Sheppey isle, the isle of Wight, and various other parts of the Essex, Kentish, Suffex, and Dorsetshire coasts. By exposing this to the air in large beds, oxygen is absorbed; the sulphur becomes sulphuric acid, and the new-formed salt is separated by washing, &c.

Much after the same manner vitriol is made from the pyrites found among coal: there are manufactories of it near Wigan, at Whitehaven, at Newcastle-upon-Tyne, and in

several other parts of the kingdom. But all the vitriol works have sunk in value of late years; the home consumption of vitriol being much diminished, since the acid, which used to be procured from the distillation of vitriol, has been obtained from the burning of sulphur. For the ancient and modern method of obtaining this acid, we refer to the article *SULPHURIC Acid*.

It is not easy to determine when this method of making vitriol was introduced into England. In the beginning of the reign of queen Elizabeth, a patent was granted to Cornelius Devoz for making alum and copperas; but it was not till towards the end of the 17th century, that this art of making vitriol was brought to so great a perfection as to enable us to export any of it; and indeed Dr. Campbell (*Surv. of Brit.* vol. ii. p. 21.) assures us, that at the latter end of the 17th century we imported annually about five hundred tons of vitriol, and that we now export upwards of two thousand tons. It appears from sir Charles Whitworth's Register of Trade, N° 1, that there were exported, from the port of London alone, near four hundred tons of copperas in three months, in 1776. A small quantity of vitriol, perhaps to the annual amount of fifty or sixty tons, says Dr. Watson, is still imported into England; some particular dyers, and other artists, being of opinion, that the foreign vitriol, as containing a little copper, is more useful to them than the English vitriol. It may be easily known whether green vitriol contains any copper, by only rubbing the vitriol to be examined upon a moistened piece of polished iron; for if there is any copper in its composition, the iron will be changed into a copper colour.

Vitriol is also prepared from mineral waters that hold copper in solution, which is precipitated by iron: this solution of iron is afterwards crystallized, and always retains some copper. In Hungary it is prepared from pyritaceous schistus, and in many places from a species of calamine; the vitriol of Goslar commonly contains a portion of zinc, as that of Hungary and Saxony does of copper; the English and French vitriols are purer, and yet sometimes contain a small proportion of alum. Turf and peat are sometimes impregnated with vitriol; other earths also often contain vitriol and alum. This vitriol is sometimes found of a white colour, on the borders of the mineral lakes of Tuscany.

Pure vitriol of iron is considerably transparent, of a fine bright, though not very deep, grass-green colour; of a nauseous, astringent taste, accompanied with a kind of sweetnessness. Dissolved, and set to crystallize, it shoots into thick rhomboidal masses, a part generally rising at the same time in efflorescences about the sides of the vessel. The solution deposits, in standing, a considerable quantity, and in boiling a much larger one, of the metallic basis of the vitriol, in form of a rusty calx or ochre: iron seems to be the only metallic body that thus separates spontaneously, in any considerable quantity, from the vitriolic acid. On exposing the vitriol itself to a moist air, a similar resolution happens on its surface; which, sooner or later, according as the acid is more or less saturated with the metal, changes its green to a rusty hue. In a warm dry air, it loses a part of the phlegm or water, necessary to its crystalline form, and falls by degrees into a white powder. Exposed to a gentle fire, it liquefies and boils up; but soon changes, on the exhalation of the watery part that rendered it fluid, to a solid, opaque, whitish, or grey mass: this pulverized, and urged with a stronger fire, continues to emit fumes, becomes yellow, being the *vitriolum calcinatum* of the London and Edinburgh Dispensatories; afterwards red, and at length turns to a deep purplish-red calx, called *colcothar of vitriol*, and the *ebullis fatiis* of the Paris Pharmacopœia, revivable

by inflammable substances into iron. This colcothar was formerly sold at Paris for ten-pence a pound, and used for giving the last polish to plate-glass, at the great manufactory in the street St. Antoine. The plate of glass, when first cast, is an inch thick; its asperities are ground away with a coarse kind of grit-stone, with sand and emery, of different degrees of fineness, and it is at last polished by colcothar. Dr. Watson suggested to the proprietors of the plate-glass manufactory, near Prescot, in Lancashire, and to the patentees for polishing marble, at Ashford, in Derbyshire, that colcothar, which is very cheap, might perhaps render the use of putty, or calcined tin, less necessary. From the colcothar of vitriol is prepared the *ens veneris*.

From the green vitriol the vitriolic acid, now called sulphuric acid, has been generally extracted; by distilling the calcined vitriol in earthen long necks, with a strong fire continued for two days or longer; though it is now mostly obtained by collecting the vapour of burning sulphur.

The distilled spirit appears of a dark blackish colour, and contains a quantity of phlegm, greater or less, according as the vitriol has been less or more calcined. On committing it a second time to distillation, in a glass retort placed in a sand-heat, the phlegmatic parts rise first, together with a portion of the acid, and are kept apart under the name of *spirit*, or *weak spirit of vitriol*, *spiritus vitrioli tenuis* of the London Dispensatory: at the same time, the remaining *strong spirit*, or *oil*, as it is called, loses its black colour, and becomes clear; in which state it is the *acidum vitriolicum* of the Edinburgh Dispensatory, and the *spiritus vitrioli fortis* of that of London; and this is the usual mark for discontinuing the rectification.

The College of Edinburgh now directs a weak vitriolic acid of more certain strength, made by mixing one part of the strong acid with seven parts of water: this is called *acidum vitriolicum tenue*, vulgò *spiritus vitrioli tenuis*. See *SULPHURIC Acid*.

Blue vitriol, or vitriol of copper, is commonly called Roman or Cyprian vitriol, or blue-stone. After being long exposed to the air, it degenerates into a mixture of blue and rusty yellow. It requires about four times its weight of water to dissolve it in the temperature of 60°. Its specific gravity is about 2.23. This salt rarely occurs crystallized, but is often found naturally dissolved in water, in Hungary, Sweden, and Ireland; from which water blue vitriol is generally prepared, by evaporating the water to a proper standard; after which it is let out into coolers, where it shoots into regular and beautiful crystals of a rhomboidal form. See *ZIMENT Water*.

It is also occasionally extracted from sulphurated copper ores after torrefaction, by the application of water, or washed out by rain or subterraneous waters. Mr. Cronstedt says it is seldom free from iron and zinc. If a piece of clean polished iron be dipped into the solution of this salt, it will almost immediately be covered with a cupreous coat: this, together with the deep blue colour arising from mixing it with a volatile alkali, discovers its basis; as its uniform mixture with other vitriolic salts does its acid. Hence it also appears, that the acid of vitriol has a greater affinity with iron than with copper, because it quits copper to unite itself with iron. This fact explains, in a very satisfactory manner, the nature of that transmutation of iron into copper, which was formerly considered as a perplexing phenomenon. Agricola speaks of waters in the neighbourhood of Newfol, in Hungary, which had the property of transmuting the iron which was put into them into copper. In the year 1673, our countryman, Dr. Brown, visited a famous coppermine at Herrn-Grundt, near Newfol; and he informs us,

that he there saw two springs, called the old and new Ziment, which turned iron into copper. The iron in this case is taken up by the water, and remains suspended in it, in the place of the copper: so that this transmutation is nothing but a change of place; and as the copper is precipitated by the iron, so the iron might be precipitated by pot-ash, or any other substance which has a greater affinity with the acid of vitriol than iron has.

The cause of the impregnation of these copper waters in Germany is not difficult to be explained. Most copper-ores contain sulphur, and, when the sulphur is in any degree decomposed, its acid unites itself to the copper, and forms blue vitriol, which is the substance with which the waters issuing from the copper-mines are impregnated. The copper contained in these waters has been for some centuries collected in Germany, by putting old iron into pits filled with the coppery water; and thus the iron is dissolved, and the copper is precipitated, and being raked out in the form of mud, it is afterwards melted into very fine copper. The quantity of copper procured by an hundred tons of iron amounts sometimes to ninety tons, and seldom to less than eighty-four. Of late years some successful attempts of this kind have been made in England and Ireland. See COPPER.

In the Isle of Anglesey, near Paris mountain, which abounds in copper ore, the water in which the roasted ore is washed is so strongly impregnated with copper, that they have found it useful to adopt the German method of precipitating it by means of old iron, and they have obtained in one year near a hundred tons of copper, precipitated from this water. The water, after the copper has been precipitated by means of iron, is at present thrown away; whereas, by evaporation, it would yield green vitriol; and as above a hundred tons of iron must be employed in obtaining the forementioned quantity of copper, Dr. Watson suggests, whether a manufactory of green vitriol might not be established at this and at all other places where copper is obtained by precipitation. One hundred tons of iron would yield, at the least, two hundred tons of vitriol, which, at the low price of 3*l.* per ton, would defray the expence of extracting it; more especially as the watery solution might be evaporated by a proper application of part of that heat, which is now lost in all the great smelting houses.

The greatest part of the blue vitriol, now met with in the shops, is prepared in England, by artificially combining copper with its sulphur or its acid. The method of making the preparation by the glass-makers is this: Take little thin pieces of brass, and lay them stratum super stratum in a crucible, with powder of brimstone. When the vessel is full, let it luted and covered in an open wind-furnace, with burning coals over it, and let it stand two hours; then let the furnace cool of itself, and take out the crucible, the mass within will be of an obscure blackish-purple; powder it and sift it fine, and then mixing with every pound of it six ounces of powdered brimstone, take a round vessel of earth, that will bear the fire, place it upon iron bars set across in an open wind-furnace, fill it with coals, and then put in the powder; keep it burning and stirring about till all the brimstone is burnt up; then take out the pan, and powder the calcined mass again; sift it fine, and proceed with it thrice as before; the last time let it stand on the fire till it becomes red. Put a pound of this calcined copper into a glass body, with six pints of water; evaporate two pints or thereabout in a sand heat; the water is then of a fine blue, and must be poured off clear; then filtrate it. Evaporate the water from the remaining sediment of copper left in the glass, and with new sulphur calcine it again and

again; repeat this five or six times, and extract the blue tincture with water as before; filtrate all the waters, and put them together. Evaporate all to a fifth part, or thereabouts, and let it in a cool place, and fine pointed crystals will be formed, resembling emeralds; separate these crystals, and evaporate the water again, till all the crystals be procured. Then put a pound of them into a glass retort, well luted, and fitted to a capacious receiver; let the joints be well closed, and make a moderate fire for four hours; then make it violent for twenty hours, or till no more white fumes arise. The next day open the receiver, and separate the liquor into a glass, where it must be kept carefully sealed up. Neri's Art of Glass, p. 50.

Very great things are to be done in the glass art by means of this liquor; the remainder in the retort exposed to the air for a few days, will acquire a blue colour, and this, mixed with zaffer, will give glass a fine sea-green. The vitriol of copper is of an elegant sapphire blue colour; hard, compact, and semitransparent; when perfectly crystallized, of a flattish, rhomboidal decahedral figure; in taste extremely nauseous, styptic, and acrid. Exposed to a gentle heat, it first turns white, and then of a yellowish-red or orange colour; on increasing the fire, it parts, difficultly, with its acid, and changes at length to a very dark red calx, reducible, by fusion with inflammable fluxes, into copper.

Some writers hold vitriol to be the root or matrix of copper; because, in the copper-mines, they never dig deeper than the glebe, out of which the vitriol is drawn. For the use of blue vitriol in medicine, &c. see VITRIOL, in *Medicine*.

The *white vitriol*, or vitriol of zinc, is found native in the mines of Goslar, sometimes in transparent pieces, more commonly in white efflorescences; which are dissolved in water, and crystallized into large irregular masses, somewhat resembling fine sugar; it is also found dissolved in mineral waters, and generally with some proportion to the vitriol of iron and copper: it is in taste sweetish, nauseous, and styptic.

It has been disputed, whether white vitriol is any thing else than green vitriol calcined. But it seems that white vitriol is of a quite different species from either the green or the blue vitriols. Geoffroy, *Mat. Med.* tom. i. p. 124.

In the condition in which white vitriol is usually bought, it contains somewhat both of copper and iron; but being purified by solution, filtration, and crystallization, it is freed from both these metals, and appears to be a native vitriol *sui generis*. See Cramer, *Elem. Art. Docim.* vol. i. p. 302. ed. 2. *Med. Ess. Edinb. Abr.* vol. ii. p. 472.

If four ounces of alum be put in concoction with two parts of cadmia fossilis pulverized, the earth of the alum precipitates, and its acid takes hold of the earth of zinc, so that a true white vitriol is the result.

This vitriol being precipitated by an alkaline ley, and dried, after its salts are separated in water, and then mixed with charcoal-duft, will give zinc.

The same thing happens in mixing vitriol of iron with two or three parts of lapis calaminaris; but the operation is easier with alum and vitriol of copper. Marggraaf, in *Mem. de l'Acad. de Berlin*, 1746.

The white vitriol requires little more than twice its weight of water to dissolve it in the temperature of 60°; its specific gravity is about 2.000. It mixes uniformly with vitriolic neutral salts, but precipitates nitrous or marine selenites from their solutions, which ascertains its acid principle; it is itself precipitated whitish by alkalies and earths, but not by iron, copper, or zinc, which sufficiently indicates its basis: if it contains any other metallic principle, this may be pre-

precipitated by adding more zinc, except iron, which will of itself precipitate by exposure to the air, or boiling in open air. That in common use is mostly prepared at Gollar, from an ore which contains zinc, copper, and lead, mineralized by sulphur and a little iron: the copper ore is first separated as much as possible, and the residuum, after torrefaction and distillation, is thrown red-hot into water, and lixiviated: it is never free from iron.

The common white vitriol of the shops contains a quantity of ferruginous matter; of which, in keeping, a part is extricated from the acid, in an ochrey form, so as to tinge the mass of a yellow hue. On dissolving the whitest pieces in water, a considerable portion of ochre immediately separates: the filtered solution, transparent and colourless, becomes again turbid, and yellow, on being made to boil, and deposits a fresh ochrey sediment; and a like separation happens, though much more slowly, on standing without heat. Hence, when the solution is evaporated to the usual pitch, and set to crystallize, the crystals generally prove foul; unless some fresh acid be added (as an ounce of the strong spirit or oil of vitriol to a pound of the salt) to keep the ferruginous matter dissolved: this addition secures the whiteness of the crystals, and prevents their becoming soon yellow in the air. White vitriol generally contains also a small portion of copper distinguishable by the cupreous stain which it communicates to polished iron immersed in solutions of it, or rubbed with it in a moist state. The quantity of copper is, indeed, very small, and may, if it be thought necessary, be separated by boiling the solution for some time, along with bright pieces of iron, which will extricate all the copper: by continued or repeated coction, the greatest part of the ferruginous matter may also be separated. For the use of white vitriol in medicine and surgery, see VITRIOL, in *Medicine*, *infra*.

VITRIOL, in *Medicine* and the *Arts*, has various applications and uses. *White vitriol* is sometimes given, from five or six grains to half a drachm and more, as an emetic, and appears to be one of the quickest in operation of those that can be employed with safety. Its chief use is for external purposes, as a cooling refrigrent and desiccative: a dilute solution of it, as sixteen grains in eight ounces of water, with the addition of sixteen drops of weak vitriolic acid, or the *aqua vitriolica* of the Edinburgh Dispensatory, is an excellent collyrium in defluxions and slight inflammations of the eyes; and, after bleeding and purging, in the more violent ones. A solution of it with alum, in the proportion of two drachms of each to a pint of water, called the *aqua aluminosa Bateana*, is used as a repellent fomentation for some cutaneous eruptions, for cleansing foul ulcers, and as an injection in the fluor albus and gonorrhœa, when not accompanied with virulence. This vitriol is sometimes likewise employed as an errhine, and said to be a very effectual dissolvent of mucous matters; in which intention it is recommended, in the German Ephemerides, against obstructions of the nostrils in new-born infants. See ZINC.

Blue vitriol, like the other preparations of copper, acts, in doses of a few grains, as a most virulent emetic. Its use is chiefly external, as a detergent, escharotic, and for restraining hæmorrhages; for which last intention a strong styptic liquor used to be prepared in the shops, and called *aqua vitriolica cerulea*. Blue vitriol has of late been considerably employed as an emetic by some practitioners; and is said to be by no means an unsafe one, as it operates the instant it reaches the stomach, before it has time to injure by its corrosive quality. The peculiar advantage in using it is represented to be, that it has no tendency to become also purgative, and that its astringent power prevents the

tone of the stomach from being impaired after vomiting with it. It is much recommended in the early state of tubercles in the lungs; and the following method of exhibition directed. (See Simmons on the Treatment of Consumptions, p. 70.) Let the patient first swallow about half a pint of water, and immediately afterwards the vitriol, dissolved in a cupful of water. The dose may be varied according to age, constitution, &c. from two grains to ten, or even twenty; always taking care to begin with small ones. After the emetic is rejected, another half pint of water is to be drunk, which is likewise speedily thrown up, and this is commonly sufficient to remove the nausea. In still smaller doses, the blue vitriol has been much used by some as a tonic in intermittents, and other diseases. See COPPER and SULPHATE of Copper.

Pure green vitriol is in no respect different from the artificial *SAL Martis*; which see. It is one of the most certain of the chalybeate medicines, scarcely ever failing to take effect where the calces, and other indissoluble preparations, pass inactive through the intestinal tube. It may be conveniently given in a liquid form, largely diluted with aqueous fluids: two or three grains, or more, dissolved in a pint or quart of water, may be taken in a day, divided into different doses. This vitriol is used also, especially when calcined, as an external styptic: the styptic of Helvetius, and, as it is said, that of Eaton, is no other than French brandy impregnated with the calcined vitriol: a drachm of the vitriol is commonly directed to a quart of the spirit, but only a minute portion of the drachm dissolves in it. (See STYPTIC.) As French brandy has generally an astringent impregnation from the oaken casks in which it has been kept, the vitriol changes it, as it does the watery infusions of vegetable astringents, to a black colour; but makes no such change in spirituous liquors that have not received some astringent tincture. See IRON, SULPHATE of Iron, and TINCTURE.

The *acid of vitriol*, or sulphur (sulphuric acid), largely diluted, is the most salubrious of all the mineral acids. It is mixed with watery infusions, spirituous tinctures, and other liquids, as an antiphlogistic; as a refrigrent in hæmorrhages; and as a stomachic and corroborant in weaknesses, loss of appetite, and decays of constitutions, accompanied with slow febrile symptoms, brought on by irregularities, or succeeding the suppression of intermittents by Peruvian bark. In several cases of this kind, after bitters and aromatics of themselves had availed nothing, a mixture of them with the vitriolic acid has taken effect: the form commonly made use of is that of a spirituous tincture; six ounces of *oil of vitriol* are drop'd by degrees into a quart of rectified spirit of wine; the mixture digested for three days in a very gentle heat, and afterwards digested for three days longer with an ounce and a half of cinnamon, and an ounce of ginger; this is the *elixir vitrioli* of the Edinburgh Dispensatory. Or, a pint of an aromatic tincture, drawn with proof spirit, is mixed with three ounces of the strong acid, so as to form the *acid elixir of vitriol* of the late London Dispensatory: these liquors are given from ten to thirty or forty drops, in any convenient vehicle, when the stomach is most empty. (See ELIXIR.) A mixture of oil of vitriol with spirits of wine alone, in the proportion of one part of the former to three of the latter, digested together for some time, has been used in France as a refrigrent in gonorrhœas, female fluors, and spittings of blood, under the denomination of *aqua Rabeliana*, and *eau de Rabel*. The acid of vitriol, diluted with water, has been given internally with great success in the itch. It was first used for this purpose in the Prussian army in 1756, and has since been much employed in several parts of Germany. The dose recommended is from

an eighth to a fourth of a drachm of the pure acid twice or thrice a day. It is said to succeed equally in the dry and moist itch; and when given to nurses, to cure both themselves and their children.

When oil of vitriol, and rectified spirit of wine, are long digested together, or distilled, a part of the acid unites with the vinous spirit into a new compound, very volatile and inflammable, of no perceptible acidity, of a strong and very fragrant smell, and an aromatic kind of taste: this dulcified part, more volatile than the rest, separates and rises first in distillation, and may thus be collected by itself. The College of London directed this *spiritus vitrioli dulcis* to be made by cautiously and gradually mixing a pound of oil of vitriol, and a pint of rectified spirit of wine, and setting them to distil with a very gentle heat: that of Edinburgh ordered the same quantity of the oil of vitriol to be dropt into four times as much of the vinous spirit, and the mixture to be digested in a close vessel, for eight days, previously to the distillation, with a view of promoting the coalition of the two ingredients. The different proportions of the acid spirit to the vinous, in these prescriptions, make no material variation in the qualities of the product, provided the distillation be duly conducted; for the smallest of the above proportions of acid is much more than the vinous spirit can dulcify, and all the redundant acid remains in either case behind. The true dulcified spirit rises in thin subtile vapours, which condense upon the sides of the recipient in straight striæ; these are succeeded by white fumes, which form either irregular striæ, or large round drops like oil; at the first appearance of which, the process is either to be stopped, or the receiver changed. The spirit which these fumes afford, very different from the dulcified one, has a pungent acid smell, like the fumes of burning sulphur: on its surface is found a small quantity of oil, called the *sweet oil of vitriol* of Hoffman, of a strong, penetrating, and very agreeable smell, readily dissoluble in spirit of wine, to a large proportion of which it communicates the smell and taste of the aromatic or dulcified spirit. The College of Edinburgh, in order to secure against any acidity in the dulcified spirit, ordered it to be rectified, by mixing it with an equal measure of water, in every pint of which a drachm of salt of tartar has been dissolved, and drawing off the spirit again by a gentle heat. This College, in their last Pharmacopeia, have manifestly shewn how little they conceive the acid to enter as a constituent part of this preparation, and at the same time have directed an effectual method of preventing its presence in it. They order the *acidum vitriolicum vinosum*, vulgò *spiritus vitrioli dulcis*, to be made by simply mixing one part of vitriolic ether with two of rectified spirit. See *Sulphuric ETHER*, and *SPIRIT of Ether*.

This spirit, taken from ten to eighty or ninety drops, strengthens the stomach and digestive powers, relieves flatulencies, promotes urine, and, in many cases, abates spasmodic strictures, and procures rest. It is not essentially different from the celebrated mineral anodyne liquor of Hoffman; to which it is frequently, by the author himself, directed as a substitute. See *LIQUOR mineralis anodynus*, *Ethereal SPIRIT*, and *Compound SPIRIT of Ether*.

The dulcified spirit is sometimes used as a menstruum for certain resinous and bituminous bodies, which are more difficultly and languidly acted upon by pure vinous spirits. It is often mixed with aromatic and stomachic tinctures, in cases where the stomach is too weak to bear the acid elixirs above-mentioned: eight ounces are commonly added to a pint of the officinal aromatic tincture; or the ingredients of the aromatic tincture are infused in the dulcified acid, instead of

common rectified spirit, in order to form the *sweet elixir of vitriol*. A medicine of this kind was formerly in great esteem, under the name of *Vigoni's volatile elixir of vitriol*, prepared by macerating, in some dulcified spirit of vitriol, free from acidity, a small quantity of mint-leaves carefully dried, till the spirit has acquired a fine green colour: and to prevent the necessity of filtration, during which the more volatile parts would exhale, the mint may be suspended in the spirit in a fine cloth. If the dulcified spirit, rectified from a solution of fixed alkaline salt, be shaken with equal its quantity of a like solution, and the mixture suffered to rest, an ethereal fluid rises to the surface, and great part of the dulcified spirit may be recovered again from the remainder by distillation. Dr. Hadley obtained the largest portion of ether, by using the strongest vitriolic acid of the shops with equal its quantity, by measure, of spirit of wine, and distilling immediately by a heat sufficient to make the mixture boil. By this management, from three pints of oil of vitriol, and six pints of rectified spirit of wine, he obtained two pints and a half of the ether.

The vitriolic acid saturates a larger quantity of fixed alkaline salts than any of the other acids, and dislodges from them such other acids as have been previously combined with them. Of the strong spirit, or oil of vitriol, about five parts are sufficient for eight of the common vegetable fixed alkalies. The neutral salt thus obtained is of a bitterish taste, very difficultly soluble in water, and scarcely fusible in the fire: in small doses, as a scruple, or half a drachm, it is an useful aperient: in larger ones, as four or five drachms, a mild cathartic. This salt has been commonly prepared with the alkali obtained from tartar, and hence called *vitriolated tartar*, and sometimes *ful enixum*, and *arcanum duplicatum*. Some dilute the oil of vitriol with six times the quantity of warm water, and drop into it a solution of the alkaline salt till no effervescence ensues: others use vitriol in substance, which being dissolved in boiling water, any alkaline salt, gradually superadded, till the effervescence ceases, absorbs the pure acid, and throws down the metallic basis of the vitriol: one part of the alkali is nearly sufficient for two of the vitriol.

With the mineral fixed alkali, this acid forms compound salts of a more bitter taste, somewhat less purgative, and much easier of solution, than that with vegetable alkalies: with volatile alkalies, a very pungent ammoniacal salt, whose medicinal effects are not well known. The strong acid, boiled on argillaceous earths to dryness, corrodes a portion of them, and concretes with them into an austere styptic salt. Calcareous earths it does not dissolve into a liquid state, but may be combined with them, by precipitation from other acids, into an indissoluble concrete, seemingly of no medicinal activity. Among metallic bodies, it dissolves zinc and iron readily; copper, silver, quicksilver, lead, and tin, very difficultly: it is fitted for acting on the two first by dilution with three or four times its quantity of water: the others require the undiluted acid, and a heat sufficient to make it boil; when, the more phlegmatic parts exhaling, so much of the pure acid matter remains combined with the metals as to render them, in part at least, dissoluble in water.

The principal use of green vitriol is in dyeing, and in the making of ink. When the vitriol is dissolved in water, the iron contained in it becomes black by the addition of an infusion of gall-nuts. Mr. Lemery, the younger, in order to account for this blackness, imagines, that as the vitriol, of which ink is made, is iron dissolved by an acid, and intimately mixed with it, and as galls are an alkali or absorbent, this alkali, meeting the acids which hold the iron dissolved,

unites with them, and makes them set the iron loose; which thereupon revivifies, and resumes its natural blackness: so that in strictness we write with the iron.

In the Swedish Transactions, vitriol is recommended as a yellow for house-painting: quicklime, made into a paste with water, is to be diluted with a solution of vitriol, more or less, according as the colour is required deeper or lighter: the mixture appears of a blueish-green colour, and does not become yellow till it is dry. One part of vitriol is said to go as far as two of the dearer yellow ochre. This salt is also recommended for preserving wood, as particularly the wheels of carriages, from decay: when all the pieces are fit to be joined together, they are directed to be boiled in a solution of vitriol for three or four hours, and then kept for some days in a warm place to dry. It is said that wood by this preparation becomes so hard and compact, that moisture cannot penetrate it. For the use of vitriol in agriculture, see SULPHATE of Iron. See on the subject of the preceding articles, Neumann's Chem. Works, by Lewis, p. 173, &c. Watson's Chem. Ess. vol. i. ess. 6. Lewis's Mat. Med. art. *Vitriolum*. Bergman's Ess. vol. i. p. 180, &c. Kirwan's Elem. of Mineral. p. 189, &c.

VITRIOLS, Metallic. All metals, it is to be observed, may be converted into vitriols, by dissolving them with acid spirits, and letting them stand to crystallize.

Fabulous vitriols, being only metals dissolved and crystallized in saline menstrua, are frequently called, by way of distinction, *metallic vitriols*, and *metallic salts*.

VITRIOL of Cobalt is found native in small pieces, mixed with a greenish efflorescence, in cobalt mines: it is difficultly soluble in water; and both it and its solution are red, which sufficiently distinguishes its basis. Its acid is known by the same taste as that of the other vitriols.

VITRIOL of Iron, *Vitriolum Martis*, is a preparation made by dissolving iron, or steel, in oil or spirit of vitriol; then evaporating or drawing off the moisture, and bringing the matter to crystallize, by setting it in a cool place. This is also called *sal martis*, or *salt of steel*.

VITRIOL of Lead. See LEAD.

VITRIOL of Luna, or the Moon, is the name given to a salt with a metallic basis, called also *Vitriol of Silver*; which see.

VITRIOL of Nickel is found native, efflorescing on kupfer-nickel, and generally mixed with vitriol of iron. This is difficultly soluble in water: both it and its solution are of a green colour. See NICKEL.

VITRIOL of Quicksilver, the name of a chemical preparation of quicksilver, with acid spirits, the process of which is this: let so rich a solution of quicksilver be made in spirit of nitre, or aqua fortis, that no more can be contained; let this solution be made by the assistance of heat, and the liquor immediately afterwards poured off into a clean and cold glass. There will, on this, spontaneously shoot on the bottom of the glass a saline, white, transparent matter, from which the liquor being poured, it is found to be a sharp, moist, saline substance, or true vitriol of mercury, soluble in water, and not safe to be touched. If the liquor, poured off from this, be evaporated half way, and the remainder set in a cool place, more crystals of the same nature with the first will shoot.

Another method of making the vitriol of mercury is this: reduce to powder some decrepitated sea-salt, and with two parts of this mix one part of crude mercury; distil the whole in a glass body, with a strong fire continued five or six hours; when the vessels are cold, break them, and there will be found a solid dry mercury, sublimed to the top and sides of the

body, in form of vitriol. Nay, Boerhaave affirms, that the common mercury sublimate is a true vitriol of mercury, though semi-volatile. Boerh. Chem. part ii. p. 301.

Vitriol of quicksilver is also a name given to a salt of mercury, mineralized by vitriolic acid, first discovered by Mr. Woulfe, together with the marine salt of mercury, at Obermoschel, in the duchy of Deux-Ponts: they have a sparkling appearance, and are either bright and white, or yellow or black, mixed with cinnabar in a stony matrix: these well mixed with one-third of their weight of vegetable alkali, afforded him cubic and octagonal crystals, that is, salt of Sylvius, and tartar vitriol. Phil. Transf. vol. lxxvi. part ii. p. 618.

VITRIOL of Venus is a solution of copper in spirit of nitre, evaporated and crystallized, to gain the salt; called also *vitriol of copper*.

VITRIOL, *Liquamen*, or *Wash of*, is a name given to the ochrey matter remaining after successive evaporations of the mother of vitriol, which yields no more vitriol. Its taste is acrid and fiery, and the quantity left from a gallon of the well-impregnated liquor from the bed is about a pound. From this may be procured a white pungent salt, by subsequent evaporations. This is the saline principle of vitriol, according to the chemists, and is contained in so large a quantity, that nearly thirteen ounces of it may be separated from a pound of the liquor; the remaining liquor, after this, is what is called *liquamen vitrioli* by some chemists, but not properly. It will never coagulate into salt, but is very fiery and acrid to the taste, and extremely ponderous, not less so than oil of vitriol, nor less pungent; and is the strongest liquor any way obtained from a natural substance without distillation. This liquor being exposed to the air in a vessel not closed, will in a little time attract double its weight of water from it. All corrosive and saline liquors have somewhat of this property of imbibing moisture from the air, and weakening themselves by it; but this liquor attracts it faster and in greater quantity than any other. This liquor receives most moisture, and increases most quickly in wet weather, less so in dry; and this may have given occasion to that error so common among uninformed chemists, that several preparations of vitriol derive moisture from the moon, and have more or less of it, according to her different phases. The changes of the constitution of the air have effected what, in this case, they supposed to be done by the different phases of the moon. Phil. Transf. No. 103.

VITRIOL, *Mother of*. See VITRIOL, in *Chemistry*, supra.

VITRIOL, *Oil of*. See VITRIOLIC ACID, infra, and SULPHURIC ACID.

VITRIOL, *Ros*. See ROS.

VITRIOL, *Saline Principle of*. See SALINE PRINCIPLE.

VITRIOL, *Spirit of*. See SULPHURIC ACID.

VITRIOLATED, among *Chemists*, turned into vitriol, or having vitriol infused in it.

VITRIOLATED Iron. See SULPHATE of Iron, and IRON.

VITRIOLATED Kali. See SULPHATE of Potash.

VITRIOLATED Magnesia. See SULPHATE of Magnesia.

VITRIOLATED Natron. See SULPHATE of Soda.

VITRIOLATED Tartar. See TARTAR, *Vitriolated*.

VITRIOLATED Zinc. See Sulphate of ZINC.

VITRIOLIC, something that has the quality of vitriol, or that partakes of the nature of vitriol.

VITRIOLIC ACID. (See SULPHURIC ACID.) This acid, when first prepared by art, was distilled from dried sulphate of iron, or the common green vitriol, or copperas of commerce: it is still prepared in Saxony, and many other parts

of Germany, from the same substance, in the manner described under *SULPHURIC Acid*. Accordingly, when the component parts neither of the salt nor of the acid were known, it was very naturally called "oil of vitriol;" acquiring this denomination probably from its resemblance to oil in adhering to the sides of a vessel containing it, and from its passing gently, or with little noise, from one vessel to another. However, as the name tends to give erroneous ideas of the nature of the acid, which is now known to be formed only of sulphur, oxygen, and water, it ought to be expunged. On account of the inconvenience and expence attending the method of procuring this acid from sulphate of iron, and the time required for the process, the manufacturers were led to the base itself, or the sulphur; which, in conjunction with nitre, was burnt in very large globes of glass, and the product was concentrated by boiling it in retorts or other glass vessels, till the fluid was of a sufficient strength for sale. See *SULPHURIC Acid*.

Mr. Parkes informs us (*Chemical Essays*, vol. ii.) that the process of forming sulphuric acid by the combustion of sulphur, was first adopted in this country by Dr. Ward, well known by his analeptic pill, white drop, and some other nostrums which bore his name. Fourcroy, however, attributes this important discovery to two French chemists, Lefevre and Lemery. Dr. Ward obtained a patent for his method of preparing it, and the article which he procured was denominated, by way of distinction, "oil of vitriol made by the bell." It is needless to describe his method, though it gave him for some time a monopoly of this British manufacture: until at length chambers of lead were employed for the combustion of the sulphur and nitre, so contrived that the floor of each might be constantly covered with a sheet of water, capable of absorbing the sulphuric acid gas at the time of its formation. The introduction of this leaden apparatus served to facilitate the manufacture of this acid, and in a short time reduced the price to about a quarter of its former rate. This important improvement is ascribed by Mr. Parkes to the late Dr. Roebuck, an eminent physician of Birmingham, who, in conjunction with his partner, the late Mr. Samuel Garbett, erected, notwithstanding a violent opposition on the part of Dr. Ward, the first leaden chamber for this purpose at Birmingham, about the year 1746: and the same works are now (1815), says Mr. Parkes, in the occupation of their successors, Messrs. Alton and Armitage. The consumption, however, was at first restricted, on account of local circumstances, to Birmingham and its vicinity. The manufacturers, therefore, with a view to a more extensive demand, and to the introduction of the article produced for the purpose of bleaching in the linen manufactories of Scotland and Ireland, established, on an extensive scale, in the year 1749, works at Preston-Pans, on the eastern coast of Scotland. It is observed, however, that Dr. Roebuck was not the sole founder of the works at Preston-Pans, or of the great iron-works at Carron. (See *CARRON*.) Of Dr. Roebuck, an account of whom has been by accident omitted under his name, it will be sufficient to observe, that he was a man of very superior talents, very considerable acquirements, and very amiable manners, highly esteemed at Birmingham, where he resided, and honoured with a peculiar intimacy with the celebrated Dr. Black. He died, much regretted, on the 17th of July, 1794. After this digression, we proceed to relate, that the doctor and his three brothers, together with Mr. Garbett, and Messrs. Cadell and Sons, of Cockenzie, near Preston-Pans, were the original projectors and founders of the vast works at Carron, to the great prejudice of their respective fortunes. This circumstance,

together with an unfortunate concern in a colliery at Borrowstonefs, brought ruin on all the doctor's fair prospects in life. With respect to the manufacture of sulphuric acid, we observe, that for several years Messrs. Roebuck and Garbett carried on their works in England and Scotland successfully and unopposed; and, besides supplying the demands of Great Britain and Ireland, exported very large quantities of sulphuric acid to the continent. At length, in the year 1756, their prospects were beclouded by the conduct of a servant, who had the art to induce a Mr. Rhodes, of Bridgenorth, to embark in the business. This person, abandoning Mr. Rhodes, connected himself with Mr. Skey, of Bewdley, who had commenced a manufactory of sulphuric acid on a much larger scale than that at Bridgenorth; and this was the third manufactory for producing the acid by the combustion of sulphur in leaden chambers. In the year 1772, a manufactory was established at Battersea, near London; and upon the failure of this, another manufactory was instituted at Pitsworth-Moor, near Eccles, in Lancashire. Soon afterwards another work was established at Leeds; and at length similar works have been founded in various parts of England, Scotland, and Ireland: and it is said, that there are now no fewer than eight considerable manufactories of sulphuric acid at and near Birmingham. When the new method of bleaching by oxymuriatic acid was introduced, about the year 1788, the demand for sulphuric acid was very considerably augmented, so that chambers for the combustion of sulphur of much larger extent than those first constructed became necessary. Chaptal, in his "*Chemistry applied to the Arts*," (vol. iii.) says, that chambers about 20 feet broad, 25 long, and 15 high, seem to be the most advantageous: and it is observed, that the size of the leaden chamber in modern use, is from 20 feet in length and 12 feet in width, to 40 or 60 feet long and 16 or 18 feet wide. One manufacturer in Lancashire, however, says Mr. Parkes, has a leaden chamber of the enormous dimensions of 120 by 40 feet, and 20 feet high, thus forming a space of 96,000 cubic feet. These leaden chambers are technically called "houfes," and in some districts "leaden vessels." The sulphuric acid annually consumed in these kingdoms is said to amount to upwards of 3000 tons, the greater part of which is used in a state of dilution, in which state it is consumed in large quantities by bleachers, and by calico-printers, for making what they call "sours;" and also for the purpose of dissolving iron or zinc when diluted with at least five or six times its weight of water.

The uses of sulphuric acid are very numerous. It is employed in large quantities for preparing the bleaching salt; by dyers for dissolving indigo, and for other purposes; by calico-printers for preparing sours; and by the manufacturing and the philosophical chemist, as a test for lead and barytes, and for a great variety of other purposes, some of which only can be enumerated.

The makers of the nitrous and muriatic acids are large consumers of sulphuric acid; as also are the makers of sulphate of zinc, sal ammoniac, phosphate of soda, Glauber and other salts; as well as the manufacturers of Roman vitriol, Prussian blue, and some other colours.

Sulphuric acid is likewise employed by some modern farmers in the preparation of their seed-wheat, to prevent what is called the smut; by the people who purify lemon-juice, when united to lime, in order to separate its acid in a crystalline form for the use of calico-printers and others; and by the makers of glass to convert the muriate of potash, which is one of their residuums, into sulphate of potash, and which has lately been used by them as a substitute for

toda. It is also consumed in large quantities by the makers of tin-plate, by brass-founders, button-makers, japanners and gilders; to all of whom this acid is become absolutely necessary for the removal of the oxyd which forms on the surface of the iron or the copper on which they work, and which, if not removed, would prevent or impede all their operations.

Sulphuric acid is likewise a necessary article to some paper-makers, to fell-mongers, and to tanners;—it is used in considerable quantities by the modern hatter in the operation of felting;—and it may be remarked that refiners use it in the process of stripping metals;—oil-merchants, in refining rape-oil, which it effects by carbonizing the farinaceous matter and the mucilage;—and brewers in fining what is called “gray beer:”—that the professors of pharmacy as well as the chemists are constant customers for sulphuric acid;—that it is employed in making the astringent and stomatic water of Rabel, and for other purposes of medicine, as well as surgery;—that distillers and rectifiers of ardent spirits consume it in still larger quantities;—that the makers of vinegar use it for the adulteration of that acid;—that many tons are annually consumed in the preparation of liquid blacking;—and that the aeronaut, at every ascension into the atmosphere, requires many hundred weights of sulphuric acid for the formation of the hydrogen gas, which renders the aerial machine buoyant in that subtle medium.

As the uses of sulphuric acid are become so various, cases may occur of its being taken into the stomach by mistake, and without immediate relief its corrosive properties would produce fatal effects. If magnesia should be at hand, that earth mixed with water and sweetened with sugar, would be the best possible antidote to the poison; but in case this could not be immediately procured, soap-water, which can be furnished by all families, and which is one of the next best remedies, should be drunk plentifully. Parkes, *ubi supra*.

For an account of the process of manufacturing this acid, and its properties, see the article *SULPHURIC Acid*. For tables, exhibiting the temperatures produced by the mixture of sulphuric acid and water, the specific gravities of the acid, when diluted with different portions of water, taken at the temperature of 60°; and of the variations in the specific gravity of concentrated sulphuric acid, by change of temperature, the barometer being at 29.5 inches, we refer to Parkes's *Essays*, vol. ii.

VITRIOLIC Acid, in *Agriculture*, is that which is now termed or known by the name of the sulphuric. It is noticed by the writer of the work on the Connection of Agriculture with Chemistry, that all acids are at present named from the peculiar bases or substances of which they are formed, by the combination of pure air or oxygen; the presence of which is necessary in all cases to constitute an acid. This is stated to be the most powerful of all the acids, and that it disengages or expels other acids, when in a state of combination with metallic, earthy, or alkaline substances in the soil or otherwise. When concentrated, it acts in a similar manner to that of alkaline salts, in the resolution or destruction of vegetable substances, as well as those of the animal kind, disengaging from them certain gases, and forming therewith certain saponeous and saline compounds. These solutions or extracts are of a reddish-brown colour, similar to that produced by the action of alkaline salts on oxygenated peat or peaty earth. The vitriolic acid may, it is said, be used beneficially to decompose and bring into action the soluble matter accumulated in soils, by the combination

of the phosphoric and forcline or oxalic acids with calcareous matter. In this case, the vitriolic acid will join with the calcareous matter, and form gypsum or sulphate of lime; while the phosphoric and forcline or oxalic acids, in consequence of their disengagement, will combine with other matters in the soil, particularly with magnesia, if any be present, forming saline matters which are very soluble, and conducive to vegetation and the growth of plants. The business is to be accomplished by the use of such substances as contain much of this sort of acid in cases where the other sorts of acids prevail.

It is suggested, however, that the endless series of processes employed by nature doth not finish or end here; for, on a supposition that the phosphoric and forcline or oxalic acids had been fully disengaged from the calcareous matter with which they had been formerly united, and that in the states of phosphate and oxalate of potash, soda, ammonia, or magnesia, they had expended themselves in the process of vegetation; still the gypsum or sulphate of lime remaining in the soil would, on a renewed application of dung, urine, animal or vegetable matter, be brought from the state of gypsum or sulphate of lime, which is insoluble, to a state approaching to that of a hepar of lime, which is soluble; and that as the vitriolic acid and calcareous matter are contained in, and form a part of, the compounded residuum of vegetable matters, it may hence be inferred, that these matters were not generated in, but were taken up, when in a state of solution, by the roots of plants. Thus, it is said, may the good effects of gypsum or sulphate of lime in America be accounted for without much difficulty. And to these beneficial effects, from the combination of inflammable substances with gypsum or sulphate of lime, forming what is called a hepar, or liver of sulphur, may be added the large share of nourishment which trefoils, and plants of a certain formation of stem and leaf somewhat of that kind, receive by the hepatic air disengaged from the hepars, when they, by the process of oxygenation, are again returned to the state of neutral salts, of which such hepars had been formed by the combination of inflammable or carbonaceous matter. See *OXYGENATION* and *SULPHATE of Lime*.

VITRIOLIC Minerals are compound fossil substances, formed of various stony and earthy particles, mixed with others of iron and copper, and that either separately or conjunctly; so that, in effect, they are ores of vitriols.

The different kinds of these minerals are, 1. The chalcitis. 2. The misy. 3. Sory or rusna. 4. Melanteria. 5. Pyrites, or fire-stone. 6. Marcasites. See *CHALCITIS*, *MISY*, &c.

In Europe, the only use made of chalcitis is as an ingredient of Venice treacle, and even here its place is generally supplied with common green vitriol calcined to a redness. The ancient Greeks used it externally in hæmorrhages, and collyriums for the eyes; also for the herpes and erysipelas; but never ventured to give it internally.

The ancients used misy for the same purpose as chalcitis, being esteemed milder than this last.

At present it is no where put to any use, nor indeed does it merit it, as containing no other virtues than those of green vitriol, though we are not sure what pernicious substance it may be mixed with.

VITRIOLIC Waters. The countries which abound with mines of copper and iron usually afford a great many vitriolic waters. See *Blue Vitriol*, under *VITRIOL*.

One of the most remarkable springs of this kind, of which we have an account, is that near Paderborn, in Germany: this is a sort of treble spring, having three openings, and all three yielding very different waters. Two of these

openings are not more than a foot and a half distant from one another, and yet of so different qualities, that the one is limpid, blueish, milk-warm, and bubbling, and contains sal ammoniac, ochre, iron, vitriol, alum, sulphur, nitre, and orpiment; all these substances having been separated in its analysis. The other is cold as ice, and is turbid, whitish, and much heavier, and stronger to the taste than the other. This holds much orpiment, with some salt, alum, nitre, sal ammoniac, and vitriol. The first of these waters is taken by the people in the neighbourhood, against worms, and disorders of the spleen, as also against epilepsies; the other is poisonous to birds, all that drink of it dying in a very little time. The experiment has been tried on common hens, with the water brought from the springs into other places, and given them to drink.

Those to which salt is given, after the swallowing of this poisonous water, struggle longer before they die by it ; and vinegar is found to save them very often from death, after drinking largely of it ; but in this case they are sickly for seven or eight days after it, and have the pip, as the good women express it.

In the dissecting of those birds which have died by drinking this water, the Lungs are always found quite shrivelled up.

The people of the country have not been deterred by this bad effect of the water from using it in medicine ; they take small quantities of it diluted in water, to destroy the worms, and it performs this very well ; but gives them a grievous sickness while it operates.

The third stream, or opening, of this remarkable spring, is about twenty paces distant from the others; the water is here very clear, of a greenish colour, and of a four, but not very disagreeable taste. It is of a middle weight, and of middle qualities between the other two, and is evidently formed of the joining of those two springs with some other fresh water in the way; for a liquor exactly resembling this third kind may be prepared, by mixing equal quantities of the other two with a sufficient quantity of common well-water.

There is a spring in Basil discharging its water through the Tanners'-street, or Gerber-gasse, which is of a blueish colour, and somewhat turbid. This holds blue vitriol, that is copper, in the form of a salt, and with it bitumen and antimony; but a much larger proportion of the first ingredient than of either of the others. The analysis of it shews, that it contains three parts copper to one of bitumen, and two of antimony. It serves the tanners of the place to good purposes, their skins receiving one of their preparations from this native water.

The fame town affords several other springs of peculiar qualities, all owing to the veins of metalline ores with which the earth of the place abounds. The one of these is called Bandulph's well, and affords a water of great use in medicine, several being regularly and perfectly cured of hydropical distempers by it. And another very remarkable one contains, as is found by its analysis, sulphur, nitre, and some gold. These, however, are in such small quantity in it, as not to prevent its being fit for the common uses of life. It is very agreeable to the taste, and is much esteemed for drinking, and sent for all over the town.

Another vitriolic water runs out of a cavern, near Gelfach, in Alsace. It is a fattish and oily liquor, and is used by the country-people for greasing their wheels, but it is fit for much better purposes. If it be boiled to the evapo-

ration of a third part, there will remain very little water, but a fatty bituminous substance, like tar, will subside to the bottom, and there will swim at the top a yellow, thin, and limpid liquor, very much resembling linseed-oil; and this, distilled in a sand-heat, yields an oily and watery liquor; the first very good for external uses, for burns &c. &c. Scalds; and the other a good internal medicine in consumptions, and other diseases of the lungs. Phil. Trans. N^o 8.

Some time ago there was a water discovered in England, that gave, on many experiments, an appearance of containing natural and perfect vitriol. This water was found near Eglingham, in Cumberland; and being examined, by adding galls to it, it became absolute ink, much deeper than any of the atramentous waters ever do; when one half the quantity was slowly evaporated, the remainder retained this quality to a higher degree than before; and on evaporating it yet farther, there concentered in it fair crystals of pure and genuine vitriol.

This was an appearance wholly new in England, and not easily accounted for, as we have no mineral, except the common pyrites, which contains vitriol; and it is very well known, that there requires a fermentation in the air, before the vitriol, contained in that stone, will be disentangled from its other principles, so as to be capable of appearing in its own form; and as this stone, lying under water, can never impregnate that water with its vitriol, it did not seem easy to conceive in what manner a genuine vitriol should be communicated to water, where there was no other substance which could give it. The suspicions that these thoughts gave the gentleman who examined this water, occasioned his making a visit to the place where it was produced, when he found that the supposed vitriolic spring was no other than an old drift made for the draining of the water from some old wrought coal-pits; the people who had worked in these remembered to have seen great quantities of pyrites there. This drift was sometimes dry for a considerable time together, and sometimes ran in a plentiful stream; and there is no doubt but that, in these dry seasons, the air acted upon the pyrites, and caused it to shoot its vitriol, which the next tide of water washed away, and it came off dissolved in it, and highly impregnating it.

This proved, therefore, no better a medicinal spring than some of a like kind, described by Mr. Leigh in his "Natural History of Lancashire;" and all these are very little better than the discovery of a medicated water in Old-street, from the remains of an old colour-shop, or Kircher's reckoning the common shores of Rome among the medicated springs of Italy.

The vitriolic spring which has been so much talked of near Haigh, in Lancashire, is no other than an accidental impregnation of common water, in the same manner: it being only the runnings of an old drift, or drain, made to carry off the water from the pits of cannel-coal; and this, like the other, as it sometimes has water, and at other times is dry, gives time for the pyrites to let go its vitriol while dry, and then imparts it to the waters that pass that way afterwards. These are not to be accounted medicated springs, since neither natural nor continual, and such may be any day made at home, by laying the common pyritæ of our clay, or coal-pits, out to moulder in the air, and then pouring water upon it, and, after a short time standing, taking it off again. Phil. Trans. N^o 245. p. 380. See ZIMENT, and VITRIOL, in *Chemistry*.

Voltaism

VOLTAISM. That branch of electrical science which has its source in the chemical action between metals and different liquids, and in the proofs which establish its identity with common electricity, the world owe principally to discoveries made by signor Volta. Its remarkable influence upon animals, which first brought it into notice, was first observed by Galvani. Hence it was first called Galvanism and afterwards Voltaism. We should have treated this subject wholly under GALVANISM, which was then more than half completed, but the latter was not finished in time to be then published. Hence the present article must rather be considered as a continuation of Galvanism, than a distinct treatise.

Galvanism concludes with a list of the different galvanic combinations, which will be terminated in this article, and the rest will be treated in succession. We have also given some account of all such facts as have transpired since the time of the publication of the first part.

TABLE shewing the relative quantity of bubbles upon the negative wire, by immersing a compound arc, of zinc and platina, into different saline solutions at a boiling heat, and at the common temperature.

Solution.	Effect.		Remarks.
	Hot.	Cold.	
Muriate of ammonia	6	3	In this and other cases, where the cypher is placed, it does not mean that no effect was produced, but that no bubbles could be seen.
Muriate of soda	2	1	
Super-tartrate of potash	4	0	
Nitrate of potash	½	0	In this experiment two combined arcs were used which just produced a sensible effect.
Phosphate of soda			
Alum	4	2	
Sulphate of potash	0	0	
Sulphate of soda	0	0	
Sulphate of magnesia	0	0	In the three last two combined arcs were tried, but no bubbles appeared.

The two preceding tables will give some idea of the relative power of different combinations of metals, and of the comparative action of different fluids.

The most powerful of the metallic combinations will be seen to be zinc with platina, gold, and silver; but zinc with copper is so little inferior, that in point of economy it will always be preferred.

Zinc with iron is, however, so near to zinc with copper, that iron might be used to great advantage where cheapness is desirable.

Zinc and copper are, in the present state of Galvanism, generally employed for the construction of galvanic bat-

teries. In the trough invented by Cruickshank, the zinc and copper plates were soldered together in pairs, so as to form so many compound plates. These plates are cemented into a wooden box, which is lined with the same cement, at such a distance from each other, as to divide the trough into distinct cells about half wide. The order of the plates should be such that all the zinc plates face one way, and the copper ones the contrary.

A great improvement has been made upon the trough of Cruickshank, by forming the cells in the trough with plates of glass. The plates of metal are soldered together by their edges, and bent at the joining, till the opposite sides become parallel, and separate from each other about half an inch. Each of these compound arcs is so placed in the trough with glass plates, that the zinc plate of each arc may be on one side of the glass, and the copper on the other, and in such order, that the zinc plate of one arc, and the copper of another, may be in each of the cells. A second improvement has been made upon this trough. Instead of a wooden trough, divided into cells with glass plates, the whole trough is made of earthenware, each trough consisting of ten cells. All the plates are fitted to a piece of wood of the length of the trough, so that they can be taken out or put into the trough all together. When they are taken out, the fluid is suffered to remain in the trough, and the plates are suspended over it upon a gibbet attached to the frame in which the earthen trough is placed. An immense battery upon this construction, consisting of 2000 pairs of four-inch plates, has been lately made for the Royal Institution. The experiments made upon it were inconceivably brilliant. The spark was so intense as to strike through a space of some lines of air, and of such dazzling splendour as to resemble the sun. Many substances were fused by the heat it produced, which had not been fused before, among which were the metal called fredium, and the earths zircon and alumine. Charcoal was made to evaporate, and plumbago to fuse in vacuo. A large electrical battery was charged by instant contact.

Since the trial of this battery, one of immense surface has been constructed by J. G. Children, esq. It consisted of twenty pairs of plates of copper and zinc, each plate being six feet square, the whole exhibiting a zinc and copper surface equal to 720 square feet. Each of the pairs of plates was united at the top by strips of lead bent into an arch, and so as to allow the plates to be exactly parallel to each other. The cells were distinct and made of wood; each pair of plates entered two cells, having the wooden division between them. The plates were all suspended from a beam above, and counterpoised to admit of their being easily let down into the liquid in the cells. The liquid consisted of water with one-sixtieth of a mixture of the sulphuric and nitric acids, which was afterwards gradually increased to one-thirtieth. Leaden pipes were conveyed from the ends of the battery to an adjoining shade out of doors, where the experiments were made.

This battery, as a source of heat, surpassed any thing

ever before heard of. It melted platinum with the greatest facility. Trisum, which had not been before melted, was fused into a globule. Charcoal was kept at a white heat in chlorine gas and phosgene gas, without any change being produced in the gas. It ignited six feet of platina wire. It was observed, that when the wire was less than a certain diameter, a less length was ignited. A view of one of the before mentioned troughs is shewn in *fig. 1*.

Since this plan is likely to become general, from its great advantage both in economy and convenience, we shall venture to suggest several improvements.

For making all the variety of galvanic experiments, it has always been a desideratum to have a battery, the surface of which may be increased in any proportion, to a certain limit, without affecting the series or number of combinations. This has not hitherto appeared practicable by any other means than that of using distinct batteries of different sizes.

A battery on the plan above described, having loose plates, will admit of the advantage here alluded to, without any other increase of expence than that of the additional plates which are meant to increase the surface at pleasure.

The cells in the earthen trough should be about an inch and a half from one dividing surface to the other, and capable of receiving plates of four inches square. Each of the cells may occasionally contain four plates, two of zinc and two of copper.

The form of the plates for this battery is represented in *fig. 2*. *Plate 1*. having a wire staple, *ab*, of the same metal with the plate. The staples must be made accurately of the same size for all the plates. A piece of wood, *ab*, (*fig. 3*.) is made to pass through all the staples of the plates. This bearer, or suspender, is divided into as many transverse grooves as there are plates, of a depth capable of receiving one-half of the diameter of the wire staple. In the same bearer are also two longitudinal grooves, *AA*, *BB*, about one-tenth of an inch wide and a quarter of an inch deep. A number of sliding pieces of brass, *aa*, are introduced into the latter grooves, equal to the number of combinations, one half of the pieces being in one groove, and the other half in the other. These pieces of metal, after being placed in proper situations, are filed down with the transverse grooves, leaving the metal above the wood, where the staple of a plate is intended to touch the metal, and filing the metal away lower than the wood, where the staple is not meant to be in contact.

After the plates are arranged upon the bearer, alternately copper and zinc, the pieces of sliding metal are made to communicate with them, that the zinc plates of one cell may communicate with the copper of the succeeding cell, the zinc of the last with the copper of the next, and so on throughout the series. The plates being all in their places and properly connected, a second piece of wood, *cd*, (*fig. 4*.) is laid upon the bearer, with correspondent grooves to fit the staples. It is covered on the under side with woollen cloth, so that when it is screwed to the bearer it serves to keep the plates secure, and at the same time preserves the connecting parts from the fumes of the acid employed in the battery. A section of the bearer, staples, &c. are seen in *fig. 4*. The whole of the apparatus complete is represented in *fig. 5*, as drawn out of the cell. *Fig. 6*. is an end view of the apparatus.

In this battery, the maximum of surface is when every cell contains two plates each of zinc and copper. When it is required to reduce the surface, nothing more is necessary than to take off the top part of the bearer, while the plates are resting in the trough, and then drawing out the lower part. If the two end plates of each cell, one of

copper and the other of zinc, be taken away throughout the whole, the bearer may be again introduced to its original situation. The battery will now consist of the same series and half the surface. If a mean quantity of surface be required, it is done by taking the end plates away from a part of the cells.

It appears, from an experiment detailed in Nicholson's Journal, vol. xxvi. p. 72, that the copper surface may be increased to advantage above that of the zinc. The experiment is as follows: If an arc of copper and zinc be made to connect two glass cups containing dilute muriatic acid, the zinc part of the arc being in one cup and the copper in the other, and if the connection be made between the two cups, to complete the circuit by an arc of copper wire, a quantity of bubbles will be evolved from the copper wire of the compound arc. If, however, instead of the copper wire the connection be made with a conical slip of copper, a very different effect will be observed, as the broad or pointed end of the slip may be next to the zinc wire. When the broad end is placed in the cup where the zinc wire is placed, a much greater quantity of bubbles appears upon the copper of the compound arc, than when the small end is placed next to the zinc. Hence it would appear, that the copper surface should be greater than that of the zinc. This may be very easily effected, by dividing the copper surface into small grooves, the sides of which make an angle of 60° , the surface will by this means be doubled. This figure might be given to the copper surface by means of a pair of fluted rollers. It will be obvious, that if the grooves are not very small, the different parts of the copper surface will not be uniformly contiguous to the zinc surface, which is a matter of some importance.

Having described the most convenient and economical method of constructing a battery, we shall now consider the means of exerting the galvanic energy so far as relates to the interposing fluid.

In the galvanic battery, there appear to be two sources from which the electricity is obtained. The one is that which arises from the contact of the metals, and the other from the chemical action between the interposing fluid and the zinc surface. The first does not require even the presence of moisture, as is shewn in the electric column of De Luc. The second is rendered greatly conspicuous by introducing between the opposite surfaces any substance capable of oxydating and dissolving the zinc.

Acids, as appears from the preceding table, are the greatest promoters of the energy afforded by chemical action, because they dissolve the zinc after it has been oxydated by the oxygen of the water. This is more especially the case with the sulphuric and muriatic acids, because these acids are not decomposed by the zinc. The nitric acid produces a still greater galvanic effect, because the acid is decomposed, and oxydates the zinc with greater facility than water. The water is also decomposed when this acid is used. Zinc hydrogen is always evolved.

The action is always increased when the conducting power of the fluid is increased. Hence it would be proper to use some cheap saline solution with the acid, which will not be decomposed by the same.

The saline solutions, alone, are very inferior to any of the acids. But from what has been observed, we may easily point out such salts as are best fitted for the purpose. All the super-salts, from their excess of acid, will answer this purpose; or such salts as are decomposed by zinc. All those salts which act upon metals by forming triple salts, such as muriate of ammonia and muriate of soda, are found to act very well in the galvanic battery.

It will be proper to observe here, that the interposed fluid does not afford a quantity of electricity proportionate to the rapidity of the oxydation, or at least the quantity of galvanic energy cannot be appreciated beyond a certain limit. If the quantity of the concentrated acid be much more than from $\frac{1}{4}$ to $\frac{1}{2}$ the weight of the water, the power of the battery will not be found to increase but from another cause, which we shall hereafter explain; the power is much sooner exhausted than when a smaller dose is used. The zinc is oxydated so slowly by saline bodies, that they may be used in saturated solutions. Potash, in a caustic state, even when much diluted with water, might be used to great advantage. At the same time that it scarcely appears to oxydate the zinc, when a single pair of wires of copper and zinc are used, the copper wire affords as much hydrogen during the contact, as could be expected from the agency of an acid. It is, therefore, highly probable, that potash or soda will be substituted for acids in galvanic experiments, as well for the sake of economy as from its being less offensive to the operator. It possesses another advantage still greater, in not destroying the zinc plates like acid solutions.

From what has been said regarding the interposed fluid, it will be easy to infer that the greatest part of the galvanic energy, which is electricity excited by chemical action, depends upon the presence of the water, and some substance which can dissolve the zinc, and at the same time give a greater conducting power to the water. The effect is not, as Sir Humphrey Davy has supposed, produced by the opposite electrical states of the elements of the compounds constituting the fluid medium, since the hypothesis is contradicted by experiment. If there wanted another experiment to decide, that the galvanic effect is as the chemical effect, the following would suffice. Take two wine-glasses, containing dilute muriatic acid, and connect them by an arc made of two wires, one of zinc and the other of platina, soldered or tied together, the zinc being in one glass and the copper in the other. If the circuit be complicated between the glasses by an arc of platina wire, no appearance of bubbles will be observed upon the platina wire of the compound arc. If, however, a small quantity of nitric acid be poured into the glass containing this wire, hydrogen gas will be immediately evolved from it, and at the same time the other platina wire in the same glass will become oxydated. This effect is not caused by the electrical agency of the nitric acid, which is decomposed; because when copper is used instead of platina, with the pure muriatic acid, the same effect takes place. It appears, therefore, that the increased effect would be attributed only to the oxydation of the wire of the homogeneous arc, in the glass containing the negative wire of the compound arc.

In every galvanic process, from a single combination to an unlimited series, no effect is observed till the circuit is complete; and during this, a current of electricity is established from the zinc surface of one combination to the copper of the succeeding. While it is passing through a metal, whatever be its length, it obeys the laws of electricity very strictly, but when it passes through a humid conductor, it appears to possess rather anomalous properties. It is proper to observe here, that conductors of Galvanism are of two kinds; the one we shall call dry conductors, and the other humid. The first class comprises all the metals, well burnt charcoal, plumbago, and the sulphurets of metals. Water appears to be essential to the second kind, holding in solution acids, alkalies, or neutral salts. Simple water has its conducting power increased by the smallest quantity of any acid, alkali, or salt. When the conducting wires of a gal-

vanic battery are made to terminate in a vessel of pure water the water will be observed to be decomposed, the oxygen being given out at the positive wire, or that coming from the zinc side of the battery, and the hydrogen from the negative or opposite wire. If the smallest quantity of an acid, a salt, or an alkali, be added to the water, the rapidity of the decomposition will be increased very conspicuously.

As it is of some importance to know the relative conducting power of water, and its different compounds, the following apparatus has been contrived for this purpose, represented in *fig. 7*. Let *eg* be a small cup of wood varnished, or, what is much better, glass; and *zc* two wires of platina distinctly inserted in the bottom of the cup, so as to be water tight. A glass tube, *op*, filled with the fluid, is inverted in the cup to receive the gas which arises from the wires *zc*, while the fluid descends, and is contained in the cup. If the cup *eg* be made larger, and of an oval shape, two glass tubes may be inverted over each wire, and the gases may be obtained separately. *Fig. 8*. *A B C D*, is a frame supporting one of the cups. The parts *G* and *F* are of glass or varnished dry wood, cemented into the parts *A B C D*, which are of brass, so that the two sides *H* and *I* of the frame are detached. The apparatus, *fig. 7*, with four others similar, are to be placed in the frame, the wire *z* being inserted into one side of the frame, and the other, *c*, resting upon the other side. When the glass tubes of each are filled with different fluids, the side *H* is connected with one end of the battery, and that of *I* with the other. Since the galvanic current must necessarily take the best conductor, the action will commence through that fluid having the greatest conducting power. If a thin bit of baked wood or glass be put under the resting part *c*, in that where the action commenced, the current will be transferred to the next inferior conductor, and so on to all the rest. By this means an accurate table, shewing the relative conducting powers of fluids, may be easily obtained.

Since the quantity of gas is the test of the conducting power, some allowance must be made when the muriates are the subject of experiment. Almost all the oxygen gas disappears in converting the muriatic into oxymuriatic acid. In a similar way the hydrogen does not appear when certain metallic solutions are employed, since it combines with the oxygen of the metallic oxyd, and the metal is reduced. When the battery is in full power, and of great extent, the relative conducting power of the fluids may be expressed by the time required for the ascending gas to displace the liquid in the glass tube. In all those experiments where the elements of bodies are transferred to different sides, the transfer takes place through any of the moist conductors, but not through any of the dry ones. No transfer can therefore be made through solid bodies, except the body be permeable to moisture. Sir Humphrey Davy, in his experiments, made use of the fibrous asbestos moistened with water. Where the fluids are required to be strictly separate, bladder answers very well as a separating medium. Animal and vegetable substances, however, abound with so many elements, that in nice experiments they would be objectionable. A vessel divided into a proper number of cells of earthenware, in the state of biscuit, would be best calculated for these experiments. This vessel should be made of pure flint and pure alumina. Should it ever become an object of manufacture to separate acids and alkalies from neutral salts, a vessel of wood, with a separation in the middle, of unglazed earthenware, would answer very well.

We shall here mention some curious facts connected with the interposition of metals, in different conducting media.

When the wires, coming from the two ends of a galvanic

battery, are brought into separate vessels containing any fluid which is a conductor. If a wire of platina, in the form of an arc, connect the two glasses together, that end of the connecting arc in the positive glass will afford hydrogen gas, while that in the negative glass will furnish oxygen gas; or, if we take all the four ends of the wires in the circuit, the positive wire from the battery will give oxygen, and that opposite to it, in the same glass, hydrogen. In the other glass, the negative wire will afford hydrogen, and the opposite wire oxygen, so that the water appears to be decomposed in each glass, since oxygen and hydrogen are furnished separately by each glass. If a number of glasses be arranged similarly, having connecting arcs of platina, and if the wires of the battery be introduced in the extreme glasses, all the ends of the wires will alternately furnish oxygen and hydrogen. No theory yet brought forward will satisfactorily account for these phenomena. Sir Humphrey Davy would assert, that each of the wires from the battery induced an opposite state of electricity in the wires opposed to them; and that in consequence the one attracted oxygen and the other hydrogen. Another theorist might hold that the electricity, which enters the first glass from the positive side, decomposes the water, and combining with the hydrogen, sets the oxygen free. The electricity and the hydrogen pass through the fluid to the opposite wire, when the electricity deserts the hydrogen, and passing through the platina arc, decomposes the water in the second glass. The oxygen is again evolved, and the hydrogen carried to the next wire, and so on through the remainder of the glasses.

A very curious experiment of the above kind rather tends to confirm the latter, than the former hypothesis. We, however, give these facts to the common stock, for the advantage of other labourers in this field of inquiry; strongly convinced that every hypothesis yet advanced falls very short of explaining all the phenomena of Galvanism.

Let the wires of a galvanic battery be made to terminate in a flat-bottomed vessel, containing pure water, about an inch and a half from each other; and if now another wire, of an inch in length, be laid longitudinally between them, but not to touch them, each end of the intermediate wire, if of gold or platina, will afford gas. That end opposite the negative wire will give oxygen, and the other end of the same will furnish hydrogen; and if any number of bits of wire be placed between the principal wires, at the same time they do not touch each other, oxygen and hydrogen will be alternately furnished by the ends of the wires. When the principal wires are brought nearer together, and a platina wire placed transversely between them, one side of the intermediate wire will furnish oxygen, and the other hydrogen. This fact is put in a more striking point of view, by placing a plate of platina in a vessel of water edgeways, and bringing the wires of the battery opposite to each other, and perpendicular to the sides of the plate. If the battery employed consist of 50 plates three inches square, a circular spot will be observed on each side the plate, opposite the wires. This appearance is caused by the evolution of gas from those parts of the plate only.

It is singular, that in all the experiments where the connecting wire was immersed in the water, if any substance, capable of increasing the conducting power of the water, be very gradually added to it, the gases given out by the intermediate wire will diminish, till they entirely cease to be produced. The wire which was transversely placed sooner ceased to afford gas, than when it was in a longitudinal position; and the effect sooner ceased with the wire than with

the plate: and in different plates, the continuance was as the size of the plate.

If the plate, however, be cut so as to divide the vessel into two portions, and the edges so completely cemented to the sides of the vessel that no liquid communication exists between the two portions, each side of the plate will furnish as much gas as the wires, whatever may be the conducting power of the fluid. If the power, which induces the plate or immersed wires to give out gas, depended upon the induction of the opposite wires, why is it not as great before the fluid is divided as afterwards? and why is it the same when pure water is used, whether the intermediate wire be immersed in the water, or is made to connect two portions of water together? These are facts which, in the present state of knowledge, do not admit of easy solution. They, however, shew us the necessity of having the cells of our galvanic batteries perfectly distinct from each other. It appears pretty clear, that that which conducts the oxygen or the hydrogen, or perhaps both, passes with greater facility through a good moist conductor than through a metal.

Decomposition of Bodies in general.—The decomposition of water and of metallic oxys was known to Cruickshank, the history of whose experiments we have already given; and in a very early stage of galvanic progress, it was observed that the alkali was separated from muriate of soda in the galvanic battery. In subjecting muriate of soda to the galvanic power in a glass tube, it has also been observed that oxy-muriatic acid was produced. The subject of the decomposition of salts, however, has been clearly made out, and established on true principles, by Sir Humphrey Davy, whose experiments have been detailed under GALVANISM. The chemical agency of bodies, arising from their relative electric states, is no doubt the cause of the decompositions of salts, and of all other bodies to a certain extent; although there are many decompositions, particularly the metallic oxys and water, which are to be attributed to some other cause much more active and expeditious. We shall here venture to draw a line of distinction between the decomposition effected by the electrical intensity arising from the contact of the bodies, and that produced by the electricity, and the hydrogen developed by the chemical agency of the oxydable metal, and the oxydating fluid.

If we take a single combination, for instance, a zinc wire connected with a platina wire, the electrical intensity arising from contact is so exceeding small, that it could hardly be appreciated by the acid of the condenser. If this combination be immersed in water, no galvanic appearance takes place, however near the immersed ends be brought to each other. If, however, we add to the water about one-tenth its weight of muriatic acid, an immense quantity of hydrogen immediately appears upon the platina wire, and continues to be evolved so long as the contact is formed, till the acid is expended. The electrical intensity, however, is the same with the water as with the dilute acid; yet the quantity of hydrogen upon the platina wire, when the acid was used, which can be attributed only to galvanism of chemical action, is much more than could be obtained by the most powerful electric machine. It can readily be admitted, from experiments in which Dr. Wollaston decomposed water by the electric machine, and from the electric effects of Deluc's column, that some water would be decomposed by the single combination, independently of the chemical action; but the difference is so glaring as to produce the strongest conviction, that the decomposition of water and the transmission of hydrogen are not dependent on the mere electric states of the wires. That the hydrogen is

transmitted from the zinc to platina, during the chemical action, many experiments seem to prove; and that the hydrogen so transmitted, by its chemical agency, and in its nascent state, is capable of effecting many decompositions, which, under other circumstances, would be impossible. In the single combination above alluded to, if the dilute acid be separated from a solution of acetate of lead, or sulphate of copper, by a piece of bladder, the zinc being immersed into the acid part, and the platina into the metallic solution, no hydrogen will be afforded by the platina, but the metal becomes reduced in proportion to the quantity of hydrogen which has disappeared: yet no perceptible quantity of this effect can be attributed to the electricity of contact, but to the mere chemical agency of hydrogen in its nascent state. Hence we are inclined to think, that the decompositions by the galvanic battery arise from two causes. Water principally owes its decomposition to the chemical action, and the agency of the electricity upon the hydrogen. Metallic oxys are principally decomposed by the presence of the nascent hydrogen, so collected and transmitted by the electricity. The decomposition of saline bodies, however, is to be attributed alone to the electrical attraction produced by the contact of the bodies employed, which can be made so great as to overcome the chemical attraction of the bodies decomposed. Of the latter of these powers of decomposition we have given some account, in detailing the ingenious experiments of sir Humphrey Davy; of the two former means of decomposition we shall say something in a practical point of view.

Many very anomalous facts were known in chemistry long previous to the discovery of Galvanism. All those chemical phenomena, under which the appearance called arborescence was observed, were inexplicable, till it was shewn from some experiments, published in Nicholson's Journal, vol. xv. p. 94, that Galvanism is the cause of these singular phenomena. In the experiment where lead is so beautifully precipitated, by suspending a piece of zinc in a solution of acetate of lead, the zinc first reduces a small portion of lead, which, with the zinc, forms a galvanic combination. The lead, if no solution of lead were present, would now give out hydrogen gas; but the hydrogen, instead of appearing in that form, combines with the oxygen of the oxyd, and the metallic lead is formed at the same point. Hence the lead appears to grow from the last point formed, which gives the appearance of vegetation. That this effect does not depend upon the presence of zinc, may be proved by the following experiment. Tie on one end of a glass tube, about half an inch wide, a piece of bladder, so that it may hold water, and fill it with a solution of acetate of lead. Into the other end insert a cork loosely, and through the cork let a platina wire pass within about half an inch of the bladder. Into a wine-glass put some dilute muriatic acid, in which place a zinc wire. When the tube with the bladder is immersed in the wine-glass, if that part of the zinc wire without the glass be brought into contact with that part of the platina wire without the tube, beautiful crystals of metallic lead will soon appear upon the platina wire. If the acetate of lead be removed, and a dilute acid be put in its place, bubbles of hydrogen will appear upon the platina wire.

Another experiment, similar to that of the lead-tree, and equally anomalous, has been long known in chemistry. If a plate of glass be smeared over with a solution of nitrate of silver, and a brass pin or a piece of zinc wire be laid in the middle of the plate, beautiful ramifications of silver will soon appear as if growing out of the pin, very much resembling

vegetation. By observing the process with a magnifying glass, each branch of this arborescence may be seen to grow from the end or side of another; which proves that the silver forming the vegetative appearance is not reduced by the oxydable metal laid on the plate, but by something at the successive points of the silver branches. With a view to ascertain this fact, one half of the plate should be smeared with nitrate of silver, and the other half with dilute muriatic acid. If a piece of zinc wire be tied to a piece of platina wire, and the compound wire so bent that the zinc may touch the dilute acid, and the platina the nitrate of silver, the ramifications of silver will soon appear upon the platina wire. That the silver is reduced by the hydrogen carried in the galvanic current, is probable from varying the experiment as follows: If, instead of smearing the plate with nitrate of silver, the whole be covered with dilute acid, and the same compound arc be laid upon it, the platina will give out bubbles of hydrogen. In the common way of making this experiment with the pin, as well as the variation above stated, it appears that the process is kept up by the galvanic current, which furnishes the hydrogen. The pin first reduces a small portion of silver, which forms a galvanic combination with the pin. The hydrogen which, but for the presence of the remaining nitrate of silver, would appear in the gaseous form, is employed in depriving the silver of its oxygen. With the compound arc, the zinc does not require to touch the nitrate of silver, because the platina with zinc is already a galvanic combination. The theory of whitening common pins can be explained only on this principle. The tin, in a small proportion, is dissolved in the tartrate of potash; pieces of metallic tin, with the pins, are also present. The two latter form the galvanic combination, and a portion of tin is reduced from the solution upon the pins, to which they owe their whiteness. We may generally conclude, that in all instances where one metal becomes the precipitant of another, the precipitation is much facilitated by the agency of the galvanic combination, formed between the precipitating and the precipitated metals, and the consequent presence of hydrogen. If a piece of zinc be introduced into a solution of sulphate of copper, the zinc in the first instance becomes covered with copper, and the effect appears to stop. If, however, a very small excess of sulphuric acid be added, the process will go on with such rapidity, that the copper becomes precipitated in a very little time. By minutely observing the process, the copper will be seen to be reduced upon that already produced, which is a proof that it is not done by the mere agency of the zinc.

It appears very evident, that when a galvanic combination of zinc with any lesser oxydable metal is placed in a dilute acid, that a much larger quantity of hydrogen will be evolved from the lesser oxydable wire, than could possibly be produced by any electrical intensity generated by the contact of the bodies employed; but that independent of this, there is an immense quantity of electricity generated during the chemical action, by which the hydrogen is transported from the greater oxydable surface to the lesser one. If the quantity of hydrogen produced depended upon the attraction of the wires for the elements of the water, this power would depend upon the electrical intensity alone, and of course upon the series in the galvanic battery, whatever might be its surface; but it is found that the power of Galvanism to decompose water is much increased by an increase of surface only.

Galvanism as a Source of Heat.—When the wires coming from the ends of a galvanic battery of considerable surface

are brought into contact, a brilliant spark is produced, and the wires stick together with considerable force, as if they were welded, or united by fusion. If the parts in contact be held with the fingers, a considerable heat will be perceived, which will be greater as the battery is more powerful, and inversely as the thickness of the wires.

Small wires seem to affect the electric fluid in a manner similar to that in which light is affected by a convex lens, or a concave mirror, by concentrating and compelling a large quantity of electricity to pass through a small channel. This appears to be the case with common electricity, as well as galvanism, since by discharging the electrical battery through very small wires, the metals become fused and oxydated.

On the galvanic battery this experiment should be made as follows: at each end of the battery should be placed a rod of metal, with a clean ball at the top of each. Between the two balls must be stretched a piece of very small wire, not exceeding $\frac{1}{16}$ th of an inch in diameter, while the circuit is interrupted in some other part of the battery. As soon as the wire is fixed, the circuit must be completed where it was broken, and the current will instantly be determined through the small wire, which will in consequence become ignited.

It was discovered by Dr. Wollaston, that, in the ignition of wire by the voltaic battery, there was one certain diameter of the wire, in which the length ignited was the greatest, above or below which the length was less. This does not arise from more heat being sent through the wire in which the greatest length was ignited, but from the ratio of the surface of the very small wire being so much greater to its solidity than in thicker wire, by which a greater proportion of heat is carried off by radiation; but when the diameter is beyond a certain extent, then a less length is ignited, from the heat being less concentrated.

It has also been found, that very different lengths of wire are heated of different metals when their diameters are equal. This appears to take place from the relative conductive powers of the different metals for electricity, which appears to be as their conducting powers for heat. Platina, being the worst conductor, has a greater length heated; and silver, which is known to be a good conductor, has a less length heated.

If the battery be very powerful, it will be fused and oxydated. When a connection is formed between the two ends of the battery, by means of the very thin foils of metals, such as leaf-gold, the metals undergo brilliant combustion, exhibiting different coloured flames. Charcoal and plumbago, presented by sharp angles, are similarly deflagrated. If the ends of the two wires coming from the battery be made to touch each side of a small globule of mercury, the latter will inflame with a bright flash. This heat, furnished in the galvanic current, is also very apparent while it is passing through moist conductors. Different fluids subjected to decomposition in the circuit, in glass tubes, become considerably heated, and this will be found the case, as the diameter of the tube is less.

Sir H. Davy attributes this heat to the decomposition, which must strike any one as being an error. Heat we al-

ways find to be evolved during combination; the very reverse of which ought to take place during decomposition.

Action of Galvanism upon Animals.—All animal substances, either dead or living, if not deprived of their moisture, are tolerably humid conductors of Galvanism. In the living subject, independent of its conducting power, it has the property of being affected in a peculiar manner. All those animals which possess excitability are affected by Galvanism as they would be affected by any other violent stimulus; and if the excitable part be at all muscular, the fibres are vigorously contracted. This causes, in a living and conscious animal, a sensation not unlike an electric shock. The shock is more like that of common electricity, as the plates of the battery are smaller and more numerous. When the plates are of very large surface, a sort of vibratory motion is felt through the part attended with a sensation of heat; and this, in a powerful battery, is felt so long as the connection is kept up. The best mode of taking the shock is first to moisten the hands, or the part where the effect is to be applied; grasp in each hand a piece of metal, such as two spoons, and touch each end of the battery with the other ends of the spoons at the same time. If it is intended to be applied to any other part, let two plates, of about two inches in diameter, be each attached to the wires coming from the battery, and let the plates be applied to some two parts: if the effect be too severe, let some inferior conductor be placed between the plate and the skin.

Sir H. Davy found, that when an animal substance was placed in the circuit of a galvanic battery, the different compounds contained in it were decomposed. This was more especially the case with the saline bodies contained in the animal fluids; the acids of the salts were found on the positive side of the battery, and the bases of the salts on the negative. Should it be ascertained that any redundancy of saline matter is the cause of disease, Galvanism might be employed with great success in separating those bodies from the system.

Dr. Wollaston has given some hints in Nicholson's Journal, from which it appears probable that the power of the glands in secreting different fluids is dependent upon the electrical state of the glands; by which they are induced to attract all bodies in a contrary state to themselves. The opinion of this ingenious gentleman has been strongly corroborated by some experiments made by Messrs. Home and Brandt. Phil. Trans.

These, however, are speculations on which we cannot at present place strict reliance. The same conjecture which is applied to secretion may be applied to the oxygenation, or rather the decarbonization of the blood in the lungs; since the carbon appears to be transferred through the membranes between the pulmonary arteries and the interior of the lungs. The same theory may be also applied to account for the change of the colour of the blood between the fœtus and the mother. Muscular excitability may perhaps arise from a certain electric state of the muscular fibre caused and kept up by the arterial blood; and if we may be allowed to carry the conjecture still further, muscular motion may perhaps be caused by the relative electric states of the muscles, and the brain and nerves.

Waggon

WAGGON, in *Agriculture and Rural Economy*, a kind of vehicle or carriage in common use. There are divers forms of waggons, accommodated to the divers uses they are intended for. The common waggon consists of the *shafts*, or *radts*, which are the two pieces the hind horse bears up; the *welds*; the *flotes*, which are the cross pieces that hold the shafts together; the *bolster*, being that part on which the fore-wheels and axle-tree turn, in wheeling the waggon across the road; the *chest*, or body of the waggon, having the staves or rails fixed thereon; the *bales*, or hoops, which compose the top; the *tilt*, the cloth thrown over the hoops; besides the *wheels*, *axle-tree*, &c.

Waggons are too frequently constructed without that proper attention to the nature of the roads, or the sorts of articles which are to be conveyed by them, which is necessary, being in general heavy, clumsy, and inconvenient conveyances. There is, however, a waggon of this kind, which is much employed in the county of Berks, that is formed and built on a more simple and convenient principle than those commonly met with in most other southern parts of the country, and which has not either the height or weight of them, while it possesses sufficient strength, and is easy in the draught. The writer of the first account of the agriculture of that district has, however, suggested an improvement to be made in it, which is that of leaving the space sufficiently deep in the body or bed for the fore-wheels to lock round in the shortest possible curve, as in the present manner of its construction, a great deal of time is necessarily lost in the turning at the ends of the swaths and plats in carrying hay or corn, as well as on some other occasions, as in this way the inconvenience may be removed without

doing the smallest injury, it is said, to the symmetry or strength of the carriage or waggon.

In the corrected report on the agriculture of that district, which has been more lately drawn up, it is however noticed, that some farmers of the forest part remark on the above, that the waggon would be much weakened by the proposed alteration; and add, that an improvement has lately been made on the waggons of this county, which is found to answer the purpose of the above suggested alteration, which is the locking chain, as it is called; which is a chain from the pillar of the waggon, to about six inches before the middle bed stay, which is made of such a length, as effectually to prevent the waggon catching on the lock. Where the beds of the waggons are straight, as is common, it is said, in the southern parts of the same county, the improvement first proposed would probably, it is thought, be useful; but that in the vale and middle parts, the beds are otherwise constructed, and scarcely admit of alteration for the better.

A waggon, too, which is peculiar to Cornwall, is said to be light and elegant, being used there for carrying corn and hay in harvest time, and faggot-wood, as well as for many other purposes. The body is open, which with a lade of five bars fixed before and behind gives it great length, while an arch put over the hind wheels gives it breadth; the fore-wheels turn clear under the body, so that it can sweep round in a very narrow compass; the load is secured by two ropes tightened by a sort of winch fixed behind the waggon; it carries about three hundred sheaves of corn at a time. A tongue tree, sometimes called a middle tree, or shafts, are

occasionally fixed to the axle of the fore wheels, according as it is intended to be drawn by an ox or a horse-team. This light waggon is thought to be deserving of a place on almost every large farm in the kingdom.

But the writer of the rural economies of the different counties of the kingdom, who has attended much to the subject, thinks that those which are employed in the county of Gloucester are to be preferred to any others in the country; as by means of crooked side rails, bending archwise over the hind wheels, the bodies or frames of them are kept low, without the diameter of the wheels being much lessened. The bodies are likewise, it is said, made wide in proportion to their shallowness, and the wheels run six inches wider than those of most other waggons, whereby advantages in carrying top-loads are, it is said, evidently obtained. Mr. Rudge, too, in his account of the agriculture of the same district, has remarked that, in many parts of it, waggons are the principal carriages employed in getting in the hay and corn, and are either full-bedded or with three-quarter beds. That the former have the advantage of a greater length of bed, but are not so convenient for turning; and that the latter, though diminished in size, have the convenience of locking the fore wheels, and turning in almost as narrow a compass as a chaise, in consequence of the bed being hollowed out on each side near the middle, to admit the exterior part, or fellows of the fore wheels. Both these sorts of waggons are capable of carrying nearly, it is said, the same weight, though the former, as being deeper in the bed, is somewhat better adapted, it is thought, for the carriage of heavy articles, such as bags of corn, and other such materials. For the purpose of carrying hay and straw, or of harvesting, their length and width are, it is said, increased by light ladders before and behind, and of similar contrivances, called "rathes," the whole length of the sides. The ladders are put on and taken off at pleasure in both kinds, but the side additions are generally fixed; except in the straight-headed sort, which are in use, it is said, on the western side of the Severn, in this county; in these they are made removeable, so as to leave the bed quite naked.

Another sort of waggon, which partakes, in some measure, of the properties of both the waggon and cart, on which account it has been appropriately denominated the *hermaphrodite*, is, it is said, frequently made use of in the county of Norfolk, when the pair of fore wheels and shafts are occasionally attached to a common cart by a pole connected with the axle, to which are added the ladders. This is, it is said, a light, cheap, and convenient sort of waggon, which is capable of carrying nearly as much hay or straw as that of the Berkshire.

As it has been observed, that from its having been long a complaint among large farmers, and others, whose business requires the constant use of carts, and only the occasional use of waggons, that the waggon, however well preserved by a shed or other such building, is daily decaying and getting worse while out of use, particularly the iron work of it, which is shortly destroyed by rust; and that, in like manner too, with those whose concerns require the almost constant use of waggons, and but the occasional use of carts; the latter, while unemployed, bear a very considerable proportion to the wear and tear of carts which are in constant use: these circumstances and effects have led and induced a Mr. Rood to devise and bring to perfection, at a very considerable expence, a contrivance of this particular kind, by which the same carriage may, in a few minutes, be made by the carter into two complete tip carts of the common dimensions, and applicable to all the uses of carts in general, or into one waggon, so complete, that a narrow inspection is, it

is said, necessary to distinguish it from a common waggon. And that there is no complication of parts in this waggon, the whole being so contrived, that none of its parts are ever out of use, consequently not liable to be mislaid or lost. The carts, too, when it is formed into them, have a contrivance by which to render them more safe and easy to the horse in going down a hill, and have moveable side ladders, which will, it is said, be found of great use in carrying corn, bark, and other such materials. It is noticed, that it may be constructed by the wheelwrights of any county or district with perfect ease and facility, and that its shape and particular dimensions are capable of being suited to the wishes of the owner, or to the local fashion of the neighbourhood in which he lives. That the result of considerable experience and enquiries enables the inventor to state that it may be completed, in any county or district, for about five pounds more than the cost of two common carts. It is admitted, however, that it is somewhat more clumsy than a common waggon.

It is united and held together by four strong pins, which are to be removed when it is disunited and used in the separated state.

A representation of it may be seen in the second volume of the "General Dictionary of Agriculture and Husbandry."

In the county of Norfolk, Mr. Douton, of Brandon, according to the writer of the corrected report on the agriculture of that district, has found a considerable saving by the use of light caravan waggons for two horses abreast, with which he carries, it is said, a chaldron and half of coals, and other loads in proportion; and that, it is thought by him, every man, who reduces the teams of any county or district, will be sure to do this until he arrives at perfection in a one-horse carriage.

In most counties, however, still much too heavy carriages of the waggon kind are in use for the business of farming as well as road purposes. In Kent, the carriages of this sort employed in conveying the corn to market and other places are large, and called hitches, being drawn by four horses; and generally loaded with not more than from seven to twelve quarters of corn, according to its weight, and the distance it is to be carried. They are thirteen feet long, are made crooked at the sides, the width cannot however be positively ascertained; but they are generally three feet wide before, and four behind at the bottom; and about six or eight inches wider at the top, being twenty inches deep: they are boarded at the sides and ends close enough to carry sand. If made with wooden axle-trees, they cost, it is said, about twenty guineas: if with iron, twenty-five. Such waggons are, however, quite unfit for many farm uses.

In Staffordshire, it has been observed by Mr. Pitt, that the reduction of the weight of waggons, in most cases, but particularly to those who are common carriers, is highly beneficial, being a gain of not less than fifty pounds a year by each team constantly employed on the road; and that if it be made with good materials a light waggon will last as long as a heavy one. The cost of a narrow-wheeled waggon there is twenty-six pounds; six inch, thirty-six; the axle-tree is most commonly of wood.

The author of the "Present State of Agriculture and Husbandry in Great Britain," remarks that waggons are chiefly used in getting in the hay and corn harvests, carrying the hay and grain to market, and bringing manure and coals from a distance. That they are generally drawn by the whole team on the farm, where one only is kept, whatever number of animals it may consist of, and that two men

and a boy are mostly necessary to attend them. That in performing distant carriages, when the roads are level and substantially made, and the waggons at all times fully loaded, one of them may probably be as advantageously used as two or more carts of less dimensions. But that where the labour is required to be performed with expedition, as in the hay and corn harvests, these unwieldy machines and contrivances are without doubt ill calculated for the purpose; and that on every occasion, when they return half or a third loaded, it is evident the farmer sustains a considerable loss. Instances have occurred to the writer, it is said, in more than one open-field parish in this part of the country, where a waggon, with three or four persons and as many horses, has been dispatched to collect and carry home scattered parcels of hay from the ends of ridges, which, after going over a great extent of the parish or district, returned only partly loaded. Considering the very high rate of labour, and the shamefully extravagant manner in which, in hay or corn harvest, labourers and farm servants are maintained in this part of the kingdom, it is surprising, it is thought, that every farmer does not exert himself to devise and find out means by which he may perform his work with greater expedition, and at less expence. There are some, however, who think that this sort of carriage or conveyance, however well formed and constructed, from its necessary great weight and unwieldiness, as well as its expence, is mostly far from being advantageous to the interest of the farmer; as while it is highly destructive to the roads, it requires great power to draw it, which must be procured at much cost, without affording an adequate compensation in the increased quantity of materials which it carries.

Waggons unquestionably require much more power in the draught in proportion than carts, which is certainly a material objection against them, though they are capable of conveying a much greater load; but, besides, they are far from being so handy and convenient for many sorts of farm-work; and some too are of opinion that more business may be done in any particular space of time, with the same number of horses, by carts than by waggons, in the general run of husbandry work, especially where the distance is small between the places of loading and unloading. That where waggons are used for farm-work, they should be made wide and low, as the most suitable in different intentions. Manures may be carried in these sorts of waggons almost as

well, it is supposed, as in carts. Broad wheels are improper for passing and repassing upon tillage lands; as if in fallow they press the land too much, making it so hard as to prevent its being ploughed until wet comes; but on grass-land, wheels of the broad kind are proper and suitable for all purposes. In Berkshire, Mr. Loveden is said to put narrow fore-wheels to his waggons, and broad ones behind, in order to prevent injury to tender grass-land. The hind-wheels in this way roll over the tracks made by the fore, and remove the mischief they have done. The method is thought to be excellent, and of very easy application.

On the whole, waggons are probably the most proper and suitable sort of conveyances for different kinds of heavy loads that are to be carried to a distance; but that for home uses, especially field and other work, which requires to be executed in a speedy manner, carts with proper shelvings and other conveniences are to be preferred, as more ready and economical. See CART.

In the work of reducing the weight of waggons for farm uses, as well as for road and other purposes, it should always be done with much care and attention, in order that it may be taken from such parts of them as have not great force of draught or pressure upon them, and that those parts which are much exposed in these ways may be left sufficiently strong. In the weight and shape of the wheels some reduction and alteration may likewise take place, as may be seen in speaking of wheels. See WHEEL.

WAGGON, in the *Military Economy*, is a four-wheeled carriage, drawn by four horses, and applied to various purposes.

WAGGON, *Ammunition*, in *Military Language*, is a waggon used in carrying all kinds of stores, and also bread; for which purpose it is lined on the inside with basket-work.

WAGGON-*Master-General* is he who has the ordering and marching of the baggage of the army. On a day of march he meets the baggage at the place appointed in the orders, and marshals it according to the rank of the brigade or regiment each waggon belongs to, which is sometimes in one column, sometimes in two; sometimes after the artillery; and sometimes the baggage of each column follows their respective column.

WAGGON-*Way*, the same with RAIL-*Way*; which see.

Wales

WALES, a large district or portion of Great Britain, situated at the north-western extremity of the island, and bounded on the north and west by the Irish sea, on the south and south-east by the Bristol channel, and limited on the east by the English counties of Monmouth, Hereford, Salop, and Chester. The length from north to south is, on an average, 150 miles; and the width from east to west 65 miles. This area comprises about 8125 square miles, or 5,206,900 acres of land: of which, it appears, by the reports to the board of agriculture, 900,000 acres are arable, and 2,500,000 under pasturage; leaving 1,700,000 acres in a state of waste, of which 700,000 acres are reported as capable of being brought into cultivation. Wales was formerly of greater extent, having for its boundaries the rivers Severn and Dee, as natural lines of demarcation. The ancient dimensions were, however, at various periods, contracted, by severing from it portions of the several counties, situated westward of those rivers; and taking out of it the whole county of Monmouth. The limits of the various districts of Wales, with the above exception, and their names, have been retained from a very remote period to the present time, independently of the modern arrangement of them into shires, as imposed by the English government. The division made in the time of

Llewelyn ap Gruffydh, the last prince of North Wales, was into the three provinces of Aberfraw, Mathraval, and Dinevwr. In the distribution of these into cantrefs or hundreds, Aberfraw comprised fifteen, which were again subdivided into thirty-eight comots, or smaller districts; Mathraval, fourteen cantrefs, subdivided into fourteen comots; and Dinevwr, twenty-four, further divided into seventy-eight comots. Nearly similar to this, is the present civil division of the principality into twelve counties, six included in North Wales; viz. Anglesea, Caernarvon, Denbigh, Flint, Montgomery, and Merioneth; and six in South Wales, viz. Cardigan, Radnor, Brecknock, Glamorgan, Caermarthen, and Pembroke. The centuriat divisions remain nearly the same as in Llewelyn's time. The whole contains 58 market-towns, and 751 parishes; and according to the enumeration made under the population act of 1811, the number of houses amounted to 123,512, inhabited by 611,788 persons; viz. 291,633 males, and 320,155 females: 36,044 families were returned as employed in trade, manufactures, or handicraft; and 72,846 in agriculture: and the average scale of mortality, according to registered burials, for a period of ten years, appears to have been in the proportion of 1 to 60 of the existing population. For the administration of justice, Wales is divided into four cir-

cuits, *viz.* the Chester circuit, including the counties of Chester, Flint, Denbigh, and Montgomery: the northern circuit, for those of Anglesea, Caernarvon, and Merioneth: the south-eastern, for those of Radnor, Brecknock, and Glamorgan: and the south-western, comprising the three shires of Cardigan, Caermarthen, and Pembroke. By a statute, passed in the reign of Elizabeth, the king was empowered to appoint two persons learned in the law to be judges in each of the Welsh circuits, which before had but one justice. And by another statute of George II., it was enacted, that where the kingdom of England is mentioned in any act of parliament, the same shall be understood as comprehending the dominion of Wales, and the town of Berwick-upon-Tweed. Wales sends twenty-four members to the British senate, one knight for each shire, and one burgess for each county-town, except that of Merioneth; in lieu of which, two towns in Pembroke-shire return a member each, *viz.* Pembroke and Haverford-west. The eldest son of the kings of England has, ever since the time of Edward I., been invested with the title of prince of Wales: and several branches of the peerage derive their titles from various places in the principality.

Ancient History, Roman Stations, and Roads.—Cambria, the ancient name of this portion of the island, is deduced by historians from the original inhabitants having been a tribe of the Celtæ, or Gauls, known under the denomination of *Cimbri*, or *Cymri*; and the Romans called the country inhabited by such people Cambria. Wales appears to have been the acknowledged name of this region in the poetry of a Welsh bard, so early as the sixth century. The derivation of the Britons from the Gauls, both Cæsar and Tacitus deduce from the vicinity of the two countries, and the similarity of the manners and character of the people: but a stronger argument is found in the national appellation of Gael and Gaul, equally attached to both countries. It appears that the inhabitants of Wales were part of the aboriginal possessors of the island, whose numbers must have been greatly increased by those Britons, who, retreating before the victorious Romans, fled to this district, as a dernier resort, to preserve their independence. After the invaders had secured the central part of Britain, by forming stations, and appointing garrisons, and had given to it the name of *Britannia Prima*, they turned their attention to the reduction of the unconquered country lying west of the Severn. When Ostorius, the Roman general, surveyed this country, which he was sent with an army to subdue, he found it possessed by three tribes of people, denominated from their respective districts, Ordovices, Silures, and Dimetæ. The *Ordovices* possessed all the country comprised in the present North Wales: the *Silures* occupied the district now comprehended in the counties of Hereford, Radnor, Brecknock, Monmouth, and Glamorgan, and the small portion of Gloucestershire now west of the Severn; and had for their capital *Caer-Gwent*, in Monmouthshire: the *Dimetæ* were situated west of the Silures, and possessed the country at present including the counties of Cardigan, Pembroke, and Caermarthen. Such were the inhabitants of Wales, when the Romans first entered it with an hostile army. Respecting the condition or state of these Britons, at the period in question, a great difference of opinion prevails among our historians. Some, in despite of unexceptionable authorities, treat these people as illiterate savages, destitute of cloaths, dwellings, and arts: while others, following the British history, describe them as a martial, learned, and flourishing nation, possessing foreign trade, and at home erecting stately edifices. Both these accounts are probably much exaggerated. The best historians state that

the Britons had a religion remarkable for its numerous ceremonies; they possessed an established government; and had regular and well-disciplined troops, divided into charioteers, cavalry, and infantry. With respect to any great naval power, though attempted to be proved by the learned Selden, well-founded objections may be urged; but as to smaller vessels, Cæsar bears ample testimony to the ingenuity of their construction, and their great convenience: the facility with which these vehicles were made, and their peculiar portability, has occasioned a continuance of their use, and *coracles* still form the fishing-boats employed on some of the rivers of Wales. They had sufficient corn for their support, and their pastures were abundantly stocked with cattle, sheep, and hogs. In their dealing with each other, for money they used rings, or small plates of iron strung together, which passed among them by weight, as well as tale: supposing they possessed no minted coins, this circumstance alone would be a sufficient evidence of their civilization; since it is deducible from history, that no nation in a state of barbarism ever adopted a circulating medium in buying and selling. From the earliest periods, the Britons breathed a spirit of genuine freedom, and always studied to procure and preserve their liberty. Stimulated by a noble ambition, never to be satisfied but by victory, nor extinguished but by death, they fought with a degree of bravery that astonished the legionary troops; and disputed every acre of ground with a tenacity and obstinacy that extorted from their conquerors the tribute of admiration. Suetonius Paulinus overcame the Ordovices, and extirpated the remainder of the Druids, and their followers, who had fled to the island of Mona, or Anglesea. Notwithstanding this, the heroic Silures for years continued their struggle for liberty, till at length Julius Agricola was sent with a powerful army by the emperor Vespasian; and having entirely defeated the Britons under their intrepid leader Caractacus, in a decisive battle near *Caer-Caradoc*, on the borders of Salop, he completely reduced that part of the island to the Roman yoke. The affability of Agricola gained the affections of the people, and disposed them to imitate the Roman manners: he bestowed on them the privileges of citizens; received them into his armies; provided for the education of their youth; and lived amongst them in a style of great hospitality. Thus, securing by policy what he had gained by force, Cambria was dignified with the name of *Britannia Secunda*: and the conquerors, as they had previously done in *Britannia Prima*, began to establish jurisdictions, and adopt measures for the due administration of the laws. Towns were built, stations appointed, and roads formed for communication between them. So speedily and successfully did they proceed in their settlement of this country, that in a few years Wales assumed all the appearance of a Roman colony. The following stations were then formed. *Caer Gybi*, Holyhead, in Anglesea;—*Segontium*, *Caer-Seiont*, Caernarvon;—*Varis*, Bodvay, in Flintshire, near Denbigh;—*Caergwrle* and *Holt*, also in Flintshire, appear to be sites of stations;—*Banchorium*, Bangor-Iscoed, on the banks of the Dee;—*Heriri Mons*, placed by Stukeley near Bala, in Merionethshire; but, with greater probability, at Tommen-y-mur, near Feltiniog;—*Caer Gai*, in the vicinity of the former place, seems also to have been a station;—*Mediolanum*, Meivod, or Myfod, in Montgomeryshire; three other places in this county seem to lay claim to such honourable distinction, *viz.* *Penalet*, near Machynlleth; *Caer-Sws*, in the vicinity of Newtown; and the *Gær*, near Montgomery;—*Magna*, Gale and Stukeley place at Old Radnor, but Horsley has removed it to Kenchester, near Hereford;—*Loventium*, Lanio-ifa, in Car-

diganthire;—*Adveigefmum*, mentioned only in the Itinerary of Richard of Cirencester, is supposed by some to have been situated at Castell Fleming, and by others near Narberth, in Pembrokeshire;—*Menapia*, the port for Ireland, near the present St. David's;—*Maridunum*, Caermarthen;—*Llanvar ar y Bryn*, in Caermarthenshire, is evidently the scite of a station;—*Leucarum*, Louchar, or Lougher, in Glamorganshire;—*Bomium*, Boverton, near Ewenny;—*Nidum*, Neath;—*Tibia Amnis*, Caerdiff;—*Gobannium*, Abergavenny, in Monmouthshire;—*Blestium*, Monmouth;—*Burrium*, Usk;—*Isca Silurum*, the capital of the colony, and residence of a prætor;—*Venta Silurum*, Caerwent;—*Ad Sabrinum*, on the Severn, near the new or old passage.

Of the *Roman Roads*, though more distinct traces might be supposed to exist in Wales than in England, from their vestiges not having been equally liable to obliteration from cultivation; yet for want of due investigation, few of them have been traced in a satisfactory manner.—*Via Julia Maritima*, which received the name of Julia, from Julia Frontinus, who successfully conducted the Roman arms against the Silures, is supposed to have connected the stations contained in the eleventh Iter of Richard of Cirencester. This road was a continuation of the Akeman-street from *Aque-Solis*, Bath; and directing its course westward across the Severn, passed through Glamorganshire, Caermarthenshire, and Pembrokeshire, to Ad Menapium, near St. David's: few traces of this road have been discovered.—*Via Julia Montana* was an upper road, forming a communication from the more central parts of the island, by the Ryknild-street, coming from Glevum, Gloucester, and passing through part of Monmouthshire, entered the county of Brecknock, proceeded over the mountains to Llanvar ar y Bryn, and thence along the vale to Caermarthen, where it coalesced with the maritime or lower road above mentioned, and both terminated at St. David's.—*Via Occidentalis* appears to have extended along the western coast of Wales, from Ad Menapium to Segontium, and formed connecting links between the intermediate stations.—*Via Devana* takes a direction through the centre of the principality from the southern coast about Nidus, Neath, to Deva, Chester.—*Via Orientalis* took a north-easterly direction from Isca Silurum, to Uriconium in Staffordshire.—A branch of the *Northern Watling-street* entered Wales at Chester, and inclining to the west, passed the station Varis, to Conovium, near Conway.—A branch of the *Southern Watling-street*, extending from Uriconium to Segontium, enters Wales near the village of Llandrinio, and proceeding to Mediolanum, is there met by the *Via Devana*; it afterwards joins the *Via Occidentalis*, and continues with it to Segontium. Numerous vicinal roads also traversed the country from station to station, vestiges of which are traceable in various places. A road of communication branched off from the *Via Occidentalis* at Penallt, and proceeded easterly to Caer Sws. Another road extended north-easterly from Llanvar ar y Bryn towards the station on the river Ythou, between which places it is discoverable on the extensive wastes in the vicinity of Llanrindod Wells. From Maridunum, a road leads to Loventium: the construction is evidently Roman, being formed of various stratifications; is about thirty feet wide, and edged with stone. Another may be traced from Llanio, running easterly by Llanvair mountain, and passing through Caio, it goes to Llanvar ar y Bryn, thence to the Gaer near Brecknock, and so to the grand station Glevum, Gloucester. In several places, having the denomination of Sarn, traces of vicinal roads are distinguishable; and wherever this British word occurs, it is probable a Roman road passed near; as Talfarn, Pensarn, and Sarnau

in Cardiganshire. Numerous villas, sudatories, aqueducts, walls, milliaria, or mile-stones, statues, votive altars, inscribed stones, tessellated pavements, urns, pottery, bricks, tiles, medals, coins, and various other remains, have been discovered, which evidently point out the vestiges of Roman residence, and by which the occupation of the country by the Romans may be clearly deduced.

Civil History of Wales.—After domineering over Britain above four centuries, the Romans bade a final adieu to the island; which was soon exposed to the inroads of numerous enemies. Assailed on the north by the Picts and Scots, it was equally infested by the Irish on the west. The native strength of the country had been exhausted by war; the number of its inhabitants further diminished by famine and pestilence; and the navy was fallen into decay. Under these disadvantages, the people were also in want of that unanimity so essential in times of emergency. They had recourse to their ancient form of government, and elected for their governors certain reguli, or chieftains; but these, instead of combining to oppose the common enemy by well-concerted plans of co-operation, were principally occupied in securing their separate interests. In this sad situation, without union, order, or discipline, and attacked on all sides by inveterate foes, the Britons adopted the most impolitic of all expedients for national safety,—that of calling in the assistance of one barbarous nation to drive out another; which subjected them to a new and heavier yoke. At this period, besides the many chieftains under whom the island was divided, a personal competition existed between one who tyrannized over the rest and held the sovereign authority, named Gwtheyrn, or (as called by most English writers) Vortigern, and a chief of Roman parentage, called Ambrosius, but by the Welsh, Emrys Wledig. During this contest, Gwtheyrn, to repel the incursions of the Scots and Picts, called in the assistance of the Saxons, an army of whom arrived under the command of Hengist and Horsa, descendants of Woden, the founder of their nation. The Saxon generals having driven back the enemy, and discovered the pusillanimity of the British monarch, turned their attention towards establishing their troops, and securing to themselves a portion of the territories they had defended: this plan, through the treachery or incapacity of Gwtheyrn, they were enabled to accomplish. The enraged Britons deposed Gwtheyrn, and placed Emrys on the throne: he for a time prevailed against the Saxons, but fresh troops arriving under the command of Ella, they became victorious, and extended their territory. On the death of Emrys, his brother Uther, commonly called, from his office, Pendragon, was elected to the sovereign dignity. The intestine warfare was carried on with varied success between the Britons and Saxons; but numerous hordes continually arriving from the north, the latter became formidable in several parts of the island. Arthur, the celebrated son and successor of Uther, for a series of years conducted the war against the invaders; and in many desperately-fought battles led on the Britons to decisive victory. During the reigns of Uther and Arthur, the ancient Britons had attained the meridian of their glory; but it was now drawing to a close: the death of Arthur decided the fate of Britain. Civil dissensions prevailed among the Britons, which were promoted by their crafty adversaries. During these troubles, many of the people submitted to the Saxons and Scots; others, to preserve their freedom, fled to Armorica, which, from the number of the refugees, acquired the name of Bretagne; some retired into the wilds of Devonshire and Cornwall; some took shelter in the mountainous parts of the north of England; but by far the

greatest number found an asylum in the fastnesses of Wales, where they defended and preserved their independence long after the expiration of the Saxon dynasty.

At the period when the Saxons had conquered the greater part of Britain, and made their approaches to the borders of Wales, this country appears to have been divided into six principalities, over which Maelgwyn, king of North Wales, was invested with the sovereign dignity, about the year 552. The contest was continued under several succeeding monarchs, till the death of Cadwallader, in the year 703, closed the imperial dignity, which for many centuries had been annexed to the British government; during which time the paramount princes chiefly resided at Diganwy, on the water of Conway, and at Caer Segont near Caernarvon. Roderic Moelwyniuc nominally succeeded to the sovereignty in 720; but by continual and unhappy divisions, the strength of the country was so diminished, as to be unable successfully to resist the incursions of the Saxons. The Mercians, under king Offa, frequently laid waste the country, and at length wrested a portion from the Welsh princes; and to prevent the new occupants from the retaliating vengeance of the Welsh, Offa caused that famous boundary to be made, from the mouth of the river Dee to the Wye, which still goes under the appellation of Clawdd Offa, or Offa's Dyke. By this the region was considerably narrowed, and nearly reduced to its present limits. Though the Saxons made frequent inroads, yet they do not appear to have had any permanent footing in the country; so that though the pages of history record many sanguinary conflicts between them and the Welsh, yet scarcely any vestiges remain to mark the incursions of the invaders. The Danes called off the attention of the Saxons from Wales, which from this circumstance was left for many years in unusual tranquillity, and furnishes but few subjects of historical record during the Danish dynasty. The Danes made some incursions on the coast, but effected no permanent conquest of the country. On the accession of William I. to the throne of England, the Welsh having refused the annual tribute, which had been extorted from them as a mark of submission by king Edgar, the conqueror invaded their country with a powerful army, quickly awed them into submission, and obliged them to do homage, and take an oath of fealty, as due from vassals to their superior lord. From this period the English monarchs preferred a claim to Wales, as their heritable property. On the death of William, the Welsh, feeling the galling yoke of their humbled condition, attempted to recover their lost independence; and joining in revolt with some refractory English barons, entered England, and by fire and sword carried their devastation to the banks of the Severn. These outrages determined William Rufus to attempt the subjugation of the country; and for this purpose he excited his barons to conquer, at their own charge, under homage and fealty to him, the territories of the Welsh. These barons, who were denominated lords marchers, endeavoured to secure their conquests, by peopling them with English, and erecting strong fortresses to defend them from the inroads of the Welsh. Thus was the last asylum of the Britons broken into on every side, and invested by their enemies. South Wales was subdued; while North Wales, now greatly reduced, alone preserved the national character, and supported its independence; and the inhabitants, aided by the valour of their princes, still upheld the struggle; and acquiring vigour from union, dictated by necessity, not only prevented the marchers from achieving further conquests, but rendered their existing acquisitions of precarious tenure. For a long period the Welsh, favoured by the mountainous nature of the country, supported an unequal but spirited

contest with their unjust invaders. The death of David, who had succeeded his unfortunate brother Llewelyn, in the reign of Edward I., closed the only sovereignty that remained of the ancient British empire. Edward having at length obtained the object of his ambition, by the entire conquest of Wales, annexed it to the crown of England. He did not, however, for some time, enjoy a tranquil possession; for three insurrections broke out at one time in different places. To such a height did these commotions arrive, that Edward was constrained to conduct the war in person, when he shortly compelled the insurgents to lay down their arms, and make an unqualified submission. These disturbances, the subsequent revolt of sir Gryffydd Llwdd, and the rebellion of Owen Glendower, were the last efforts the Welsh made to recover their independence. From that period the concerns of the country, till the time of Henry VII., are little interesting; for the inhabitants were reduced to a state of the severest bondage. Henry VII., from the assistance the Welsh had afforded him in obtaining the crown, was more favourably inclined towards them than preceding monarchs, and granted the principality considerable immunities. Several ameliorating statutes were passed in the reign of Henry VIII., to exonerate them from the tyrannical oppressions of the lords marchers; and at length the people, awake to their true interest, solicited the king to give his liberal designs a more salutary effect, by extending to them all the privileges of the English jurisprudence. The prayer of their petition was granted, and Wales was formally united and incorporated with England.

Wales abounds with the remains of encampments, hill-fortresses, castles, and castellated mansions: specimens of military architecture, therefore, in the diversified styles of different and distant periods, constitute some of its most prominent and interesting features. While the Romans generally chose for the site of their camps, or forts, a rising ground near some river, or a lingua formed by the confluence of two; the Britons selected the most lofty, insulated, and inaccessible mountains, the summits of which they fortified by excavating deep trenches in the solid rock, adding valla, by heaping up the loose stones dug out of the fosses; and in succeeding times, by adding strong walls, and erecting massy circular towers. The Normans introduced a new style of military fortification; and to secure their unjustifiable seizures, and proceed in their aggressions, they erected castles, more formidable both in number and extent, so that what are termed the marches of Wales consist of a series of fortresses from the mouth of the Dee to the embouchure of the Wye. Flint, Denbigh, Montgomery, Powys, Brecknock, Caerphilly, and Caerdiff, furnish bold examples of the style of those people. More were erected by the Anglo-Normans, as they progressively encroached on the country; for, to secure the conquered possessions from the retaliating vengeance of the expelled owners, they were necessitated to repair and strengthen the fortresses they took, or build others. Thus did these buildings so far increase, that Mr. Pennant enumerates 143 castles in the principality; and that number is probably short of the actual amount. On the conquest of Wales by Edward I., that monarch, who had been crusading in the holy land, and had there imbibed a spirit of eastern magnificence, for the purpose of overawing his new but refractory subjects, constructed three castles in a style, which for strength and grandeur have never yet been surpassed in this country. Harlech, Caernarvon, and Conway, remain the proud monuments of that monarch's age and times.

Ancient Constitution, Government, and Laws.—From the accounts given by the Roman writers, a monarchical form

of government was prevalent among the early Britons. The island was divided into several petty sovereignties, each subject to a separate prince; but in time of emergency and danger, they were united in one, under an officer, similar to a dictator among the Romans, called a *pendragon*. To him, by joint consent, was committed the whole military government of the independent states. Nor was this dignity temporary, like the power; for though the latter appears to have ceased with the necessity that demanded it, yet the former continued for life, and was hereditary to the male heir. But the right of succession to the separate governments does not seem to be strictly indefeasible; for, in some instances, the lineal succession was violated by the rule of tanistry. By this the king's son, brother, or nephew, became the customary inheritor of the crown; the particular person being selected by the reigning monarch, with the advice of his nobles. This sovereign elect was denominated by the law the *tanist*, or second in dignity. The Britons were not unacquainted with that rational restraint on monarchical despotism, parliamentary suffrage; for a decisive argument in favour of the existence of British parliaments is found in the preface or introduction to the laws of the great Cambrian legislator, Howel Dda. Six of the most intelligent and powerful persons were summoned out of every cantref, or hundred, to assist the king in the great work of legislation. This parliament being assembled, proceeded to examine the ancient laws, cancelled some, reformed others, enacted new ones, and digested all into one regular code of jurisprudence. This revision they presented to good king Howel, who having approved it, gave the ratifying sanction of royal authority. Both the monarch and parliament then imprecated the power of the state and the wrath of heaven upon any persons who should violate, or attempt to abrogate, any of these institutes, unless they should be constitutionally annulled in a national council, similar to the one in which they had been recently decreed. From the circumstances of this revision, many of those in the code of Howel Dda were pre-existent statutes, by which the early Britons had been regulated in previous times. From these it appears, that immediately below the sovereign ranked the *Uchelwys*, or great men holding their lands from the crown, and each presiding as lord over his particular domain. As immediate tenants of the king, they were obliged to perform certain services. Inferior to these, and holding from them as feudatory lords, were the general mass of the community, being in a state of villinage, but divided into two classes: first, such as might retain or relinquish their lands at discretion, possessed the power of buying and selling, and whose feignorial service was the least degrading of the menial kind; the other, denominated *Caeths*, were considered the property of the lord, attached to the soil, and saleable with the estate. These were bound to services the most servile, to build or repair houses for the *Uchelwys*, and perform all the drudgeries of husbandry. Both were subject, like the chiefs, to military attendance in time of war, and to contributions in money or kind. Such were the tenures of lands in Wales, prior to the introduction of English customs, as appears by the laws of Howel Dda, not formed by him, but referable to previous institutes, ascribed to the early Britons. And as they were evidently feudal in their essence, and military in their design, the opinion of antiquaries, who deduced the introduction of a system of feuds into this island from the Normans, must be erroneous; for the laws in which it is found to have existed in Wales were collected into a digest, in the early part of the tenth century. The most prominent feature in the Howellian code is the law of inheritance, denominated *gavel kind*, by which the property

was divided among the sons; the females of every degree being excluded till the utter extinction of the males, among whom no distinction was made between the legitimate and the spurious. While the Welsh preserved their independence, this law of descent universally prevailed; but on the conquest of the country by king Edward I., he directed certain commissioners to inquire upon oath into all the former laws and usages of the principality; and the first law promulgated by that monarch for the use of Wales was the celebrated statute of *Rhyddlan*. By this he permitted the ancient stem to continue, but lopped off two of its principal branches, *viz.* the admission of spurious offspring to the inheritance, and the preclusion of females. But in the 34th year of Henry VIII., the venerable trunk was for ever levelled with the ground, all the lands in Wales having been required "to be holden as English tenures to all intents." Since which period the laws of England, with the exception of a few formal peculiarities, have continued to form the jurisprudence of Wales.

Ecclesiastical History, Religion, &c.—The religion of the Britons, when Cæsar first visited the island, was of a kind peculiar to them, and to the kindred tribes of Gaul. It abounded with singular tenets, and the mode of worship comprised numerous superstitious rites, the remaining vestiges of which form some of the most interesting antiquities in the country. *Bardism*, or the Druidical system as it is generally called, has been variously represented; and the term *bard*, given to the Welsh poets who were not of the Bardic order, has tended to increase the confusion on the subject. What may be considered as the foundation of the order was the principle of universal benevolence, so that a bard was prohibited by his tenets from bearing arms; and being recognised as the herald of peace, he could pass, when clad in his azure robe, unmolested from one hostile country to another. The bards were divided into three classes, the *bard braint*, *ovydd*, and *derwydd*. To the bards braint belonged the perpetuation of the customs and privileges of the system, and of its moral and civil institutes; the *ovyddon*, or oviates, particularly attended to the cultivation of the arts and sciences; the *derwyddon*, or *druids*, were the priests who officiated in religion: from which circumstance, and from the great influence they consequently obtained over society, this class was most conspicuous, and became the general denomination of the whole.

Their origin, learning, religion, authority, revenues, decline, and extinction, have been fully detailed in this work under the article DRUIDS.

In the sixth century, the archiepiscopal seat of Wales was removed from Caerleon to Menevia, which was subsequently known by the appellation of St. David's. At that time the archbishop had under him three suffragans, the bishops of St. Asaph, Bangor, and Landaff. In the tenth century, St. David's lost its archiepiscopal honours; and in 1101, it became subject to the metropolitan see of Canterbury; to which, on the subjugation of the country by Edward I., the whole of Wales, as to ecclesiastical affairs, submitted; and at the dissolution of monasteries, the Welsh having been subjected to the English laws, the clergy in Wales were brought under the same regulations as those in England. And from the close incorporation of the two countries, the history of the church, after that time, is nearly similar in both. In Wales are many sects of what are considered regular Protestant dissenters from the established church, which had their rise in the reigns of James I. and Charles I., and more especially during the protectorate of Oliver Cromwell. But the greatest number of seceders from the established church are the different descriptions of Methodists, whose places of

assembling, multiplied over the face of the country, receive the appellation of chapels. Of this increasing dissent, one reason is assigned to be the generally illiterate state of the regular clergy: for most of the livings in Wales are so small, and the stipends of curates so scanty, that no inducement is held out for youth being properly instructed for the ministry, and consequently the churches must be served by incompetent ministers. But this evil is likely soon to be remedied; for by the zealous endeavours of the present worthy bishop of St. David's, two seminaries are instituted for the education of youth designed for holy orders, who are provided with tutors. Most places in Wales have the benefit of a free-school; and in the year 1749, for the instruction of the children of the lower orders, 142 itinerant schoolmasters were appointed by the society for promoting Christian knowledge. Those among Protestant dissenters have been provided for in this respect by the pious bequest of Dr. Daniel Williams, many years the respectable pastor of a congregation in London, who left a large sum of money for establishing charity-schools, where such institutions were wanted; by virtue of which the trustees have erected many in the principality.

The lovers of *ecclesiastical, monastic, and sepulchral architecture*, will find ample scope for amusement and admiration, in the remains of religious edifices, both in an integral and dilapidated state, still visible in various parts of the principality.

Mountains, Lakes, Rivers, and Climate.—Wales exhibits all the features of a detached district from England, consisting of almost continued ranges of lofty mountains, and impending crags, intersected by numerous deep ravines with extensive valleys, and affording endless views of bold, wild, or romantic scenery. To enumerate the mountains which are nominally known to the natives, and form very striking objects to the traveller, would be superfluous; but a general view of them, as they are grouped with multifarious ramifications, may be useful. The chains generally extend in a direction from south-east to north-west, having their escarpment, or most abrupt declivity, on the latter bearing. Numerous projecting ridges laterally expand on various parts of the compass, in countless ramifications, many of which are surmounted by lofty eminences, that are formed into so many distinct mountains, so that, like the Alps, they seem to be mountain piled upon mountain, and hills conglomerated upon hills. The principal range in North Wales is that denominated the *Snowdonian* chain, from the lofty mountain Snowdon occupying its centre. Commencing at Bardsey island, in the south-west extremity of Caernarvonshire, the line, varied at irregular intervals by conical peaks, extends in a north-easterly direction to the promontory of Penmaen-bach, in the bay of Conway. The intermediate parts consist of the loftiest mountains in Wales. The *Ferwyn* chain occupies the eastern part of Merionethshire, and branches out into Denbighshire. Its length is about sixteen miles, and the breadth varies from five to ten: Cader Ferwyn, Cader Frowen, and the Sylattin, are the most elevated points. Another line branches off into Montgomeryshire, and joins the Breddin chain, extending into Shropshire. Another chain, or rather a continuance of the same, extends in a south-west direction from Pennant, near the vale of Tanad, in Montgomeryshire, to the sea-coast near Langyllin in Merionethshire. In this extensive ridge are conspicuous several lofty mountains, known under the appellation of the Arrans and the Arrenigs; the most eminent of which are Arran-ben-llyn and Arran-fowddy, and the extremity of the line is grandly marked by the triple head of the lofty Cadir Idris. The celebrated *Plinlimmon*

proudly elevates his crest above a range of table land, extending from the vicinity of Llanvair in the north-east, till they decline in the south-west, and end in the abrupt cliffs, which bound part of the bay of Cardigan, near Aberystwith. Among particular elevations in this line, after the sovereign of the group, the Carno mountains stand the most pre-eminent. South Wales, though not equally mountainous with the northern part of the principality, nor so distinguishable for its Alpine heights, is yet far from being deficient in elevations and depressions. An extensive chain of mountains stretches from Bleddva forest, north-east of Llandrindod Wells, in Radnorshire, crosses the northern part of Brecknockshire, continues in a south-westerly direction through Caermarthenshire, and terminates in the conspicuous ridge of the Prescelly or Prescelau mountain in the county of Pembroke. The Fothoc hills, on the eastern side of Brecknockshire, commence another line, principally known under the general appellation of the *Black Mountains*, from the appearance given to them by the dark vegetable covering of heath and ling. Among individual elevations, remarkable for their height, are Tre-beddw mountain, Pen Mallard hills, the black mountains strictly so denominated, and the high table land which in the south part of Caermarthenshire is closed by the isolated mountain, called Pembre hill. In this mountainous region, *lakes* are exceedingly abundant; an attempt to describe, or even to enumerate them, would be endless: Mr. Gough reckoned from fifty to sixty in Caernarvonshire only. The most distinguished for extent, or the beauty of the surrounding scenery, are, in North Wales, Llyn Nantle, Llyn Cywellin, Llynian Llanberis, and Llyn Conway, in Caernarvonshire; with Pimble-meer, and Tallylyn, in Merionethshire. In South Wales, Llyn Bychlyn, in Radnorshire, and Llyn Savathan, or Langor's pool, in the county of Brecknock.

Rivers.—Wales, though a mountainous country, is equally remarkable with England for its numerous streams, which issuing from considerable lakes, or aided by their waters, meander through the country, and form excellent harbours at their confluence with the sea. The principal rivers are the Severn, the Wye, and the Towy, in South Wales; the Conwy, the Clwydd, and the Dee, in North Wales: these have not only attained pre-eminence in fame for the utility of their navigation; but, by poets, have been celebrated in song. The former constitutes the eastern, and the latter the north-eastern boundary of the country, between the embouchures of which many others, though less distinguished in a commercial point of view, are highly valuable for their fisheries and other properties. These, tracing their sources in the order in which they unite their waters with the ocean, are, in North Wales, the Ogwen, Sciont, Gwynedd, Drwydd, Avon, and Dovey; in South Wales, the Rheidiol, Ystwith, Eiron, Tivy, Nevern, Gwyn, Cleddy, Itrog, Taf or Tave, Loughor, Tawy, Nedd, Avon, Taf or Taffe, Rhymny, and Usk. A particular description of the most considerable, will be found under their respective names.

The *climate* of Wales differs materially from that of the portion of England, lying in the same parallel of latitude; and assimilates more with the northern parts of the island. In a general view the air is sharp; in the mountainous parts bleak; moderately mild in the vales, and those parts adjacent to the ocean, especially on the southern coast, and particularly in the celebrated vale of Glamorgan. From the greater degrees of cold prevalent in the Cambrian atmosphere, snow is more frequent in Wales than in England, lies much deeper, and is seen covering the tops of the highest mountains, for many months in the year. The wet season in this country is not usually confined to the winter months;

for rains are frequent at all times of the year. The gaged quantity of rain which annually falls in England, according to the experiments of Dr. Hales, is about twenty-two inches; while the average that descends in Wales may be estimated at thirty-four. From numerous observations respecting this subject, the result has uniformly been, that more falls on the western than on the eastern side of the kingdom, and most in the mountainous districts; consequently Wales must participate largely in such an excess of humidity. In the year 1802, the quantity of rain which fell in London was fifteen inches, and in Brecon twenty-six inches. Moist as the climate of Wales must consequently be from this vaporous state of its atmosphere, yet the air is in general highly salubrious, and the country healthy. Scarcely a cemetery in the principality, but bears some testimony to the longevity of the inhabitants, even to the protracted age of a century, and in some instances even to a greater extent.

Natural Productions and Minerals.—Few countries can vie with Wales in the multifarious variety of its productions, while none perhaps have been so long and undeservedly neglected. Some animals, rarely to be met with, frequent the wilds of this diversified country. The goat is here found in its ferine state, and is far superior in size, and in the length and fineness of his hair, to that of most other mountainous countries. Though this useful animal has been long domesticated, yet many of the inhabitants of North Wales suffer the goats to run in a wild state, and bound from crag to crag. These they are accustomed to kill during autumn for the sake of the fat and skins: thus goat-shooting and goat-hunting are still practised by the people in Wales. Roebucks were anciently numerous, but are now confined to the most intricate parts of the country, and they are rarely to be seen. Of the feathered tribes, many species, not found in other parts of the island, are to be met with here. The golden eagle is an inhabitant of the Snowdonian mountains, which thence are supposed to have derived their appellation of the Eagle rocks. The peregrine falcon, supposed to be the bird which furnished the amusement of falconry to our ancestors, and formed a sort of criterion for nobility, breeds abundantly among the rocks of Llandidno, in Caernarvonshire. The merlin, used in hawking, migrates from Wales to England generally in September. The water rail is found in Anglesea, early in the spring; and immense flocks of puffins visit the island of Prielholm about the same time. The guillemot, and the black-backed gull, frequent the Welsh coast during the winter. Among the numerous fish, which abound in the rivers of Wales, in addition to those generally known in England, may be noticed the crooked perch found in Llyn Raithlyn, Merionethshire, and the deformed trout, said to be peculiar to a brook, called Syrcian, in Cardiganshire: (these two species are described by Daines Barrington, in a communication to the Royal Society 1767): also the samlet is frequent in the upper part of the Severn and the Wye; the sewin, the red char, the silver char, and the gwiniad. Some of these, however, are not exclusively peculiar to the principality, but are found in some of the rivers of Scotland, and in the lakes of Westmoreland and Cumberland.

The mineral productions of Wales form the most interesting part of the subject, and furnish an inexhaustible source of profitable investigation to individuals, and of national wealth. The mountains and hills may be separated into three distinct classes, viz. primitive, secondary, and derivative, which in a general view may also be distinguished by the peculiarities of their form, as well as their relative situation. Primitive granite mountains consist of craggy

steep rocks, tending in the ascent more or less towards an acute or slender pointed summit, the loftiest mountains are centrally situated in the chain, which commencing and terminating in abrupt precipices, with the insulated peaks that interrupt the general outline, form a striking and distinctive character. Secondary mountains, chiefly composed of schistose substances, range next in the scale, and are distinguishable from the former by their inferior height, the evenness and squareness of the individual links which compose the chain, and by the easy waving though varied line of the general contour: instances of which are conspicuous in the Ferwyn and Breddin mountains previously noticed. Derivative, or calcareous and siliceous hills, range considerably lower than the secondary or slate mountains, usually rising by a gradual ascent at one extremity, and terminating abruptly at the other. The lime-stone hills frequently assume a pyramidal shape, while the ridges of the sand rocks, and banks, are broader and rounder than those of lime. These, however, often trap into each other, and then little dissimilarity is discoverable in their form. The primitive mountains in mass contain no metals; copper is however found in several of the horn-stone stratified mountains, of which the Parys mine, and those at Llanberis and Pont-Aberglaslyn, are examples. In these mines, the ore is for the most part yellow, sulphuret of copper, the green and blue malachites or carbonates of copper, are found in lime-stone, as at Ormes-head and Llanymynech hill, where copper is not produced in any other state but that of carbonate, which is also found in the calcareous cement of sand rocks. The strata generally most productive of the metallic ores are lime-stone; and most species of whin-stones, or the argillaceous mountain rocks, of which there are many varieties appearing in thick, thin, and mediate strata; some of these rocks are moderately and others exceedingly hard. They assume various colours, though principally one or other of the numerous shades of grey. Several rich and valuable mines are discovered in granite or moor-stone mountains. These three orders or classes of rocks, with their concomitant strata, are usually intersected by mineral fissures, and contain the largest quantity of mineral substances, and metallic ores. But of all classified strata, in which the richest mineral veins have been discovered, the indurated argillaceous mountain rocks are the most prolific and extensive. Many of the mines in North Wales, nearly the whole of the numerous valuable lead mines in the county of Cardigan, and most of the mines in other parts of South Wales, are found in this kind of matrix or strata. The principal subterraneous substances produced in Wales, may be divided into three classes, metalline, mineral, and lapideous; and the places where they are dug receive the distinctive appellations of mines, pits, or quarries. *Silver* is obtained in considerable quantities, though not at present found in what may be exclusively denominated silver mines. Cwmlymlog mine in Cardiganshire consists of silver ore, lead ore, and quartz; which, from the rich produce of the more precious metal, received the appellation of the Welsh Potosi. Daren vawr, Daren vach, Goginan Cwm Eryn, and Mynydd bach, contain similar substances to those of Cwmlymlog, though not equally productive of silver. Llanvair is at present the richest mine worked in the principality; comprising silver, lead, quartz, spar with a small portion of copper, and yields about one-sixth of lead ore. About sixty to eighty ounces of silver are extracted from a ton of ore, and twelve hundred and a half weight of lead. *Copper*, which was known and appreciated by the Romans while in possession of Britain, is abundant through different parts of the island, but was not an object of commercial investigation till within

about two centuries past; nor in Wales to any considerable purpose till the middle of the last. The copper works of the Romans lay for ages neglected; and to the public and enterprising spirit of Nicolas Bailey, the country owes the revival of research for this valuable metal. Parys mountain in Anglesea consists wholly of copper, either in a state of native copper, sulphate, black ore, or malachite: the matrix is a dark grey chert, and the superstratum aluminous slate. The copper ore found at Llanberis in Caernarvonshire, is of a very superior quality to that of Parys mountain, yielding from eight to ten *per cent.* weight of metal. This ore subsists in the primitive stratified rocks, and generally in a matrix of schistose hornblende, or quartz. The same mountainous ridge, consisting principally of whin and horn-stone, divided by the immense chafin over which is thrown the bridge called Pont-aberllynn, contains another copper mine producing ore similar in quality to that of Llanberis; and it is highly probable the whole of this district is pregnant with copper. Esgair vraith mine in Cardiganhire consists of copper ore, spar, quartz, and a substance, termed by the miners gozin, which forms an envelope to the quartz. *Lead*, for which this island was always famous, is found in a variety of places through Wales, but particularly in the counties of Flint, Caernarvon, Montgomery, Caermarthen, and Cardigan; indeed the latter may be considered as the most extensive and richest mining field in Britain. A mineral tract stretches from Pen-yr-allt, or Bryndigri, in a line to the western borders of the parish of Holywell in Flintshire, and is known under the name of Whiteford rake. The ores differ in quality; the lamellated, or common kind, usually named potter's ore, yields from fourteen hundred to sixteen hundred and a quarter of lead, out of twenty hundred of the ore: but the last produce is rare. The veins are found either in chert or lime-stone rocks, and some of the best ore has been dug at the depth of ninety yards. In this tract several levels have been driven and shafts sunk, and lead continues to be obtained in very considerable quantities. Between Gwydir and Capel Cerrig in Caernarvonshire, within an extensive dip between lofty mountains, are very extensive lead works. The surrounding rocks consist of slate, bituminous shale, and trap or whin; the matrix of the ore is quartz, and calcareous spar; they produce lead and calamine, mixed with iron ochre, and a small quantity of copper pyrites. These different substances are so blended, that in the same specimen a variety of them may be found. But Cardiganhire may be peculiarly denominated the region of lead mines, the whole country apparently having its rocks cemented together with veins of this metal. For a vast extent the land is excavated, and the surface covered with the opening of mines already worked, or the vestiges of numerous others that have furnished their subterraneous treasures to remote generations. The principal lead mines in this county are Cwm-yfwith, Llewerneg, Inys Cynvelin, Penybanch, Bron-y-goch, Llwywnwch, Grogwion, Gellan Erin, and Nant-y-Crier. The ore found in most of the Cardiganhire mines is nearly of a similar nature, consisting chiefly of lead, mixed with quartz and spar, accompanied frequently with quantities of an ore of zinc, denominated by the miners, from its dark appearance, black jack. This, which formerly was appropriated to the repair of the roads, has lately been discovered to be a valuable article, constituting an excellent flux for brass; and, mixed in due proportions with copper, makes a hard metal, similar to the orichalcum of the ancient Romans. *Iron*, the most useful, and through the wise distribution of Providence, the most common of all metals, is plentifully dispersed over the British isles; and Wales is not deficient in this particular. Yet, notwithstanding

ing the mountains of this country are full of iron-stone, it was not till within about half a century, that the public attention was turned to this inexhaustible source of internal wealth. Iron is most abundant in South Wales, though evident marks of its exilience may be traced in North Wales; and it has lately been procured, and works erected in the vicinity of Ruabon in Denbighshire. The several species of iron which have been discovered are hematites, kidney ore, or compact brown iron-stone; grey ore, or black iron-stone; bog ore swampy iron-stone; and a variety of sulphurated and arsenical ores, which class under the general denomination of pyrites; but the kidney and grey ores are the most frequently found. The principal iron works are Merthyr Tydvil, Aberdare, and Cyfartha, in Glamorganshire; and the Union, Llanelly, Beaufort, and Hirwan, in Brecknockshire. *Coal* is found in every county of Wales except Cardigan, Merioneth, and Caernarvon. The coal sometimes underlays the calcareous strata, or, in the miner's phrase, has a lime-stone roof; but more frequently it is found on the northern or southern side of a lime-stone ridge; and when a tract of low land is included between two such ridges, it may be inferred, that coal lies beneath. Two parallel lines of calcareous strata extend through South Wales in an easterly direction, from St. George's Channel across the whole country. These are accompanied by two lines of coal. Upon the upper line, coal has been found at Johnston, Picton, Jeffreston, and Begeley, in Pembrokehire. Thence keeping on the southern side of the lime-stone ridge, it crosses the Towy, forming the bar at the mouth of that river; and passing through the upper part of Caermarthenshire, Brecknockshire, and Monmouthshire, crosses the Severn to the collieries of Kingwood near Bristol. The different species of coal in Wales are the newcastle, the rock, the stone, or splent, the cannel, or parrot, and the culm, or blind coal, denominated in England Welsh coal, because almost peculiarly the produce of Wales. Some varieties of the cannel coal are so fine and solid in the texture, and so susceptible of a high polish, as to be capable of being turned in the lathe, and formed into various utensils, toys, and trinkets. The schistose mountains of Wales afford another substance, if not of equal importance, yet of general utility. *Slates*, customarily called Cornish tile, because originally procured from Cornwall, constitute an elegant and useful roofing to houses much cheaper than lead, for which it is latterly become a very common substitute. Slate quarries are numerous scattered over the country, but the principal are those of the Rhaidol near Aberystwith, Cardiganhire; Llangynnog, Montgomeryshire; and the extensive ones in Snowdonia, Caernarvonshire. Those of the former place produce specimens of the large and coarsest kind of slate, which lie in compact masses, resembling flag-stone, of a rough texture, but separating easily into large plates. Llangynnog slate also divides into large plates, is not of quite so coarse a quality, and forms a very profitable building article. These quarries, Mr. Pennant observes, yielded from November 1775 to the same month in the following year 904,000 slates, which were sold from six to twenty shillings per thousand. The Snowdonian slates are generally of a very fine grain, a beautiful blue colour, and when quarried separate into exceedingly thin laminæ; properties, which render them particularly eligible for handsome roofing, and manufacturing into writing slates. So great have been the quantities of late years procured from this district, that a small insignificant creek has been dignified with the name of Port-Penhryn, from the export trade of this article only. On viewing the different apertures of the schistose moun-

tains, a striking geological fact will result, correspondent with the principle of uniform though unequal declivity. It is observable that the strata are always coarsest in their texture on the northern or north-western sides of the ridge, and less so on the south and south-western sides; becoming gradually finer as they approximate the lime-stone hills. Wales affords numerous quarries of other valuable stones; viz. different kinds of marble fit for monuments, columns, chimney-pieces, and other ornamental sculpture; serpentine and other species of horn-stone; chert or petrifaction, and pure quartz, for the use of the potteries. Nor should that rare and curious substance be omitted, which furnishes the asbestos, indestructible by fire, found on the shores of Anglesea. The mona marble, from the isle of Anglesea, is now much used in chimney-pieces and fancy furniture. (See MARBLE, *British*.) The Britons, as already observed, understood the use of metals, and were further instructed in the arts of mining by the intelligent Romans; but after the departure of the latter, self-preservation occupied the attention of the natives, and peaceful science sunk under the devastating hand of war. Yet their mines were not wholly neglected, for it was probably by means of this subterranean wealth, that the Welsh were enabled to support against the English an unequal warfare for so long a time. During centuries after the conquest, in England the crown asserted its exclusive right to all mines and minerals; and no person could search for ore unless empowered by a royal grant, under conditions imposed at the discretion of the monarch. Edward I., on his conquest of Wales, extended his mining authority over that country; and it does not appear that the proprietor of the land, on which a mine was opened, had any share in the profits, till the reign of Henry VI., when the duke of Bedford having obtained a lease of all mines containing any gold or silver, a reservation was made of a twentieth part of the proceeds to the owner of the land. Queen Elizabeth, however, adopted a sound policy: she sent over for some experienced Germans, and granted letters patent to them and their heirs for ever, to search for and conduct the business of mines, through several specified English counties, and the whole principality of Wales. The patentees divided part of their tenure into shares for sale; and with the purchasers of such shares, they were incorporated by the style of the "governor, assistants, and commonalty of the mines royal." But though the foundation was thus laid for the present success in mining, yet little of importance was effected till the reign of Charles I. According to the testimony of Schlutter, the lead mines in Flintshire were not worked before the year 1698, when Dr. Wright and his associated adventurers established a smelting-house at Halkin. The subsequent extension of mining concerns was encouraged by the repeal of former restrictive statutes, and by the enactment in the first year of William and Mary, that persons having mines shall enjoy the same, although claimed as royal mines; the king having the right of pre-emption in the ore at certain regulated prices.

Agriculture, Bridges, Roads, and Canals. Wales in a general view may be considered a century, at least, behind England in its state of agriculture. The mode of ploughing, the course of crops, the deficiency of manure, the want of draining, and the rude implements of husbandry, are ill calculated for making a progress in agricultural amelioration. Many of the errors evidently arise from the ignorance, prejudice, indolence, and poverty of the tenants; but other causes are attributable to the proprietors of estates. One is, not granting proper leases, the lands for the most part being let from year to year: a still more injudicious custom is the

letting farms by auction. But though this is the general state of agriculture, yet striking and honourable instances occur, in divers places, of more rational conduct. Many gentlemen are setting the example of the most improved practice; and almost in every county, associations of intelligent agriculturists have been formed for the introduction and encouragement of a better system of husbandry. From the nature, as well as number of the rivers in Wales, the erection of bridges must have excited, at an early period, the attention of the Welsh. Insurmountable barriers must have been opposed to the traveller, without the aid of what may be termed pendent bridges; that is, such as are thrown from crag to crag, at a prodigious height above the water. Of this kind is the bridge, or rather two bridges, called Pont-ar-Mynach, near Hafod, in Cardiganshire, forming a pass over an awful yawning chasm, through which the river rolls its waters to the Rheidiol. Another, called Pont-aber-glas-lyn, forms a communication over a narrow defile in the mountainous ridge separating the counties of Caernarvon and Merioneth. Numerous bridges, of a single arch, are scattered over the country; of this class is the celebrated Pont-y-Prydd, crossing the boisterous Taffe in Glamorganshire. Among those bridges composed of more than one arch, the triangular-arched bridge over the river Dee at Llangollen, is curious for its mode of construction, and great antiquity: the bridge across the Conwy, near Llanrwst, is an elegant structure, and does honour to the skill of its architect, Inigo Jones: the bridge of five arches at Bangor-Iscoed, in Flintshire, is a fine specimen of architecture. The town of Caermarthen is entered by a long ancient bridge; but the stupendous aqueduct, by which the continuation of the Ellesmere canal is carried over the Dee, at Pont Cyffyllte, between Llangollen and Chirk, in Denbighshire, is the chef d'œuvre of this species of architecture; and can only be exceeded in grandeur or utility, by the projected bridge over the Menai straits, by which it is proposed to form a land communication between the county of Caernarvon and the island of Anglesea. Wales, though long famed for its bridges, was, till of late years, nearly a stranger to good roads. Except the two great mail-roads, forming the communication with the north and south of Ireland, by the way of Milford and Holyhead, whence the packets sail for that country, scarcely a road could be found, calculated for the passing of carriages. But to this essential point for profit and convenience, the land proprietors have recently directed their attention with the most beneficial effects; and the country may now be traversed in almost every direction. Under the auspices of that public-spirited nobleman, the late lord Penrhyn, a grand road has been cut through the immense range of lofty mountains, denominated Snowdonia, by which an extensive communication has been opened between the internal parts of North Wales and the coast; and the great thoroughfare from London to Dublin by way of Holyhead diminished in length, compared with the former one by way of Shrewsbury and Conway, twenty-five miles. Numerous roads have been widened, shortened, and otherwise improved, by the addition of drains, arches, bridges, &c. to the great accommodation of travellers, and general benefit of the inhabitants. Already has the country begun to experience the advantages by new communications having been opened for the produce of the interior, in the reduction of the rate of carriage, and in the easy access thus afforded for the conveyance of ponderous articles to the sea-coast, or to the inter-communications with the navigable rivers by inland canals.

Improvement by internal navigation was long neglected in this country, though equally capable of such advantages

as England. In North Wales, the first project which engaged the attention of the landed interest, was the junction of the navigation on the rivers Severn and Dee, by opening an aquatic communication through the counties of Denbigh and Flint, with various ramifications into the mining and manufacturing districts in the adjacent counties. This is called the Ellefmere canal, connected with which is the Montgomery canal. Those in South Wales are the Kidwelly, Cardiff and Merthyr Tydvil, Aberdare, Neath, Brecknock, and Swansea canals. For a particular description of each, see their respective names under the article CANAL.

Manufactures, till within these few years, were not very extensively diffused, nor could be considered of much account in the general scale of productive industry. Wales, however, has for centuries been celebrated for its flannels, and may be considered as standing unrivalled in this useful article. The woollen substances manufactured are webs, flannels, stockings, wigs, gloves, and socks. Webs are distinguished by the trade into two sorts; the strong or high country cloth, and the small or low country cloth. Strong cloth is made in Merionethshire, and principally in the vicinity of Dolgelly and Machynlleth: at the latter place is a manufactory upon a small scale, a circumstance only worthy of notice, as forming the commencement of a change in preparing the wool, which will probably soon become general. The standard width of this cloth is seven-eighths of a yard; the length of a piece, or what is emphatically styled a web, is about 200 yards; the quality is of various degrees. Small cloth is the produce of Denbighshire; it is chiefly manufactured within the parish of the Glynn, a large tract of country including Llangollen and Corwen. This article is about one-eighth of a yard narrower than strong cloth; the length is the same. Flannel constitutes the most important of the Welsh manufactures: it is chiefly the produce of Montgomeryshire; but by no means confined to that county, being made in various places within a circle of about twenty miles round Welshpool. A manufactory of note has been established a considerable time at Dolobran; and two on a large scale have been recently erected near Llanydloes, where the various machines, used in the woollen trade by the English, are applied to the purposes of manual labour. The principal markets for webs and flannels are Welshpool and Shrewsbury; the quantity made is not easily ascertained. Mr. Pennant, in his *Snowdonia*, published in 1781, mentions, that there were brought "annually to Salop 700,000 yards of webs; and to Welshpool annually between 7 and 800,000 yards of flannel." Stockings, wigs, socks, gloves, and other small knit articles, are sold chiefly at Bala, Merionethshire, being made in that town and neighbourhood. Stockings, to the amount of from two to five hundred pounds worth, are sold each weekly market-day. Very considerable manufactories of cottons and cotton twist have been established in the counties of Flint and Denbigh, the principal of which are Northop, Greenfield, Sceiving, Newmarket, and Denbigh. In some of these factories cotton yarn is spun of so fine a texture, that 130 hanks, each being 830 yards in length, make but a pound weight. Numerous manufactures of copper, iron, lead, tin-plates, &c. have also been recently set up in various towns both in North and South Wales. *Commerce* may justly be considered at present in its infancy, being chiefly confined to the coasting trade. Except Caernarvon and Swansea, which have lately extended their views to Spain, Portugal, and the West Indies, few of the Welsh ports possess vessels of very considerable tonnage; though no part of the island contains a greater proportion of harbours and roads, some

of which are safe and good, and more might soon be made so, by the building of piers and other improvements, which are obvious at the respective places.

Peculiar Customs, Superstitions, &c.—Among a variety of Welsh customs, those in courtship, marriage, and at funerals, excite particular attention. Hymeneal negotiations are frequently carried on by the Welsh peasantry in bed: the young swain goes sometimes several miles to visit the object of his choice at her residence; the lovers retire to a bed-chamber, and between the blankets converse on those subjects which the occasion suggests. This usage is confined to the labouring classes of the community; and is scarcely ever productive of those improprieties which might naturally be expected. Previous to the celebration of a wedding, a friend undertakes the office of a bidder; who goes round the neighbourhood to invite all persons of nearly the same situation of life as the contracting parties: in consequence, the friends and neighbours for a great extent make a point of attending the wedding, laden with presents of money, butter, cheese, and other provisions; these are carefully recorded by the clerk of the wedding, opposite to each respective name, and are to be repaid in the same public manner, on similar occasions, whenever demanded. This custom is called *pwrs a gwregys*; and making the presents is termed paying *pwyddion*. As an ancient usage, it is considered as recoverable by law; but a sense of the reciprocal duty generally prevents litigation. Funerals in Wales are attended by greater crowds of people than even their weddings. When the procession sets out, every person kneels, and the minister repeats the Lord's prayer. At every cross-way, the same ceremony is repeated, till they arrive at the church; the intervals of time being filled up by singing psalms and hymns. A remarkable custom prevails, in some parts of Wales, of planting the graves of departed friends with various evergreens and flowers. Box-thrift, and other plants fit for edging, are planted round in the shape of the grave for a border, and the flowers are placed within, so that the taste of the living may be known by the manner of embellishing these mansions of the dead. The snow-drop, violet, and primrose, denote the infant dust; the rocket, rose, and woodbine, shew maturer years; while tansey, rue, and star-wort, mark declining life. Each has its little evergreen, fond emblem of that perennial state where change is known no more. It has been observed, that mountainous scenery is peculiarly friendly to those aerial and imaginary existences which constitute the objects of superstition. This is exemplified in Wales. The belief of witchcraft is still strong, and many are the fatal effects supposed to be produced by supernatural agents: at every house may be seen a horse-shoe, a cross, or some charm of defence. Many old women, on account of their age, and perhaps deformity, bear the odium of preventing the cows from yielding milk, and of inflicting disorders on men and cattle. The supposed witches find it their interest to deny nothing that is alleged to them; and thus become held in superstitious fear by the people, and obtain a livelihood from their imagined extent of power. The belief of those elvish beings called fairies appears to have been ancient and general, and is not yet wholly eradicated. In some degree connected with fairies, is another species of supposed aerial beings, called knockers: these, the Welsh miners say, are not to be seen, but are heard under ground, in or near mines, and by their noises, which represent the different stages in the progress of mining, generally point out to the workmen a rich vein of ore. An opinion is prevalent within the diocese of St. David's, that previous to the death of a person, a light is sometimes seen to proceed from the house, and pursue its

way to the church, precisely in the track that the funeral will afterwards follow. This is traditionally attributed to the special prayer of St. David, that no one in his diocese should die without this intimation of departure, which is called *Canwyll corph*, or the corpse candle.

Language, &c. — The Welsh language has an undeniable claim to very high antiquity, as a dialect of the Hebrew, spoken by the descendants of Japhet: in its formation, as well as grammatical construction, it has a near resemblance to the original tongue; and is, perhaps, without exception, the most primitive and uncorrupt living language in the western world. It abounds with original words, more especially technical terms, which other languages borrow from the Greek, or express by circumlocution, and is said to be peculiarly fitted for poetry. The orthoepy of the Welsh is very different from that of the English. In the language of Cambria are forty-three letters; sixteen of which are radicals, expressive of the primary sounds; and the rest may be considered as serviles, because used as inflexions or mutations of the former; for each of these there is an appropriate character. But the language is gradually getting into disuse, especially in the southern part of the principality. The gentry of the country are principally educated in England, and consequently few of them speak it, and many wish for its extermination. The example of the higher classes extends, and ere long the language and manners of Cambria may coalesce with those of the inhabitants to the east of the Severn. See grammar attached to Owen's Dictionary of the Welsh Language, which contains an ample critical dissertation, &c. 2 vols. 4to. 1803.

Poetry was in high estimation among the ancient Britons: Wales, as their place of refuge, was early the seat of the poetic muse, and modern effusions of original genius evince that she has not deserted her favourite mountains. In no nation, except the Hebrew, was genealogy considered of so much importance, or carried to an equal extent, as in Wales. Family distinction is pursued so far, that perhaps it induces the Cambrian to think more highly of himself than is rational. Pride of ancestry was a delicate and essential point among the ancient Britons, and consequently they were more desirous of noble than of rich connections. So deeply was this principle rooted, that even the lowest classes of the people carefully preserved the descents of their families, and were in general able from memory not only to recite the names of their proximate progenitors, but to trace their various relations back through numerous generations.

Whoever reads the history of the most ancient inhabitants of this island, the Cambro Britons, will find innumerable instances of the reverence which they paid to their poet-musicians, the bards, both of Pagan and Christian times; and songs of very high antiquity have been preserved in the Welsh language, though not all the tunes to which they were sung. The harp, with which these songs used to be accompanied, was in such general favour in Wales, as to be

regarded among the possessions necessary to constitute a gentleman. (*Leges Wallicæ*.) The most ancient Welsh poetry that is now intelligible was written about the year 1100, and some of the tunes that are preserved in the late Mr. Morris's MS., which were transcribed from the music-book of William Penllin, the harper in queen Elizabeth's time, are supposed by Dr. Davies (*In Præf. ad Græm. Brit.*) to be coeval with the verses to which they were sung, when he composed his grammar and catalogue of ancient Cambro-British songs. Unluckily the notation, or tablature, in which these tunes have been written, is so uncommon and difficult to reduce to modern characters, that though the gravity or acuteness of the several notes can be ascertained, yet their lengths, or duration, cannot be established with any degree of certainty, by any rule which we have been yet able to devise.

The northern annals abound with pompous accounts of the honours conferred on music by princes who were themselves proficient in the art, and the Cambro-British institutes, with laws and privileges in favour of its professors. As the first musician, or bard, was the eighth officer in dignity, at the court of the Welsh kings, and had a place in the royal hall next to the steward of the household, so the respect and dignity with which bards in general were treated about this time, in all the courts of Europe, were equal to those which Homer tells us their predecessors Demodocus and Phemius enjoyed in Greece. Music was now a regal accomplishment, as we find by all the ancient metrical romances and heroic narrations in the new-formed languages of the times; and to sing to the harp was necessary to a *perfect prince* and *complete hero*.

The first Greek musicians were gods; the second heroes; the third bards; the fourth beggars! During the early times of music, in every country, the wonder and affections of the people have been gained by *surprise*; but when musicians became numerous, and the art was regarded as easier acquirement, they lost their favour, and from being seated at the tables of kings, and helped to the first cut, they were reduced to the most abject state, and ranked among rogues and vagabonds.

For more particular accounts of different parts of Wales, the reader is referred to the names of the twelve counties: *viz.* ANGLESEA, BRECKNOCKSHIRE, CAERNARVONSHIRE, CAERMARTHENSHIRE, CARDIGANSHIRE, DENBIGHSHIRE, FLINTSHIRE, GLAMORGANSHIRE, MERIONETHSHIRE, MONTGOMERYSHIRE, PEMBROKESHIRE, and RADNORSHIRE. — Hoare's *Giraldus Cambrensis*, 2 vols. 4to. 1806. *Beauties of England and Wales*, vol. xvii., North Wales, by Rev. J. Evans, 1812. Ditto, vol. xviii., by Rev. T. Rees, 1815. Warrington's *History of Wales*, 2 vols. 8vo. 1788. Malkin's *Scenery and Antiquities of South Wales*, 2 vols. 8vo. 1807. Aikin's *Journal of a Tour through North Wales*, 12mo. 1797. Evans's *Tour through North Wales*, 8vo. 1802. Ditto *through South Wales*, 8vo. 1804.

Waterwheel

Machines actuated by the Force of Currents or Streams of Water.—These are very numerous, but all may be reduced to two kinds.

First, those which are adapted to receive the impulse of moving water; that is, water which has been put in motion in consequence of a descent towards the earth previously to its operating on the machine, which must be provided with parts proper to resist and take away some of the motion of such water, and it will thereby receive motion which may be applied to produce some mechanical effect. Of this kind are undershot and horizontal water-wheels.

Secondly, those machines which are provided with some kinds of buckets or vessels to contain water, the weight of which buckets, and the water they contain, is supported by the machine, so that the water cannot descend towards the earth in consequence of its gravitation, without giving motion to the buckets or vessels which contain and support it. Of this kind is the over-shot water-wheel, breast-wheel, chain of buckets, and pressure-engine.

In either case, the motive force or power is the same; viz. the gravitation and motion of such bodies or masses of water as are found more elevated above the surface of the earth than the general level of the sea, or of some other water in its neighbourhood; such water will descend by the force of gravity until it joins the sea, or until it is supported or held up by some fixed obstacle.

The difference between the two kinds of machines is, that in the first case the water is suffered to descend before it operates upon the machine, and in consequence of its gravitation, acquires motion with a velocity proportioned to the space through which it has descended; and the office

of the machine is to take from the moving water as much of its compounded weight and motion, or power, as it can obtain.

In the other case, the machine receives its motion and power at the same time, when the water acquires it, by descending; or, in other words, the machine moves with the water.

The word *power*, as used in practical mechanics, signifies the exertion of strength, gravitation, impulse, or pressure, so as to produce motion; and a machine actuated by means of strength, gravitation, impulse, or pressure, compounded with motion, is capable of producing an effect: and no effect is properly mechanical but what requires such a kind of power to produce it.

The muscular power of animals, as likewise pressure, impact, gravity, electricity, &c. are looked upon as forces, or sources of motion; for it is an incontrovertible fact that bodies exposed to the free action of either of these are put in motion, or have the state of their motion changed. All forces, however various, can be measured by the effects they produce in like circumstances; whether the effects be creating, accelerating, retarding, or deflecting motions: the effect of some general and commonly observed force is taken as unity.

The most proper measure of power is the act of raising some weight with some velocity of motion; that is, the overcoming of the gravitating force of a weight in such degree as to produce motion in opposition to gravity. In considering the quantum, the weight or mass of matter operated upon must be one quantity, and the velocity of the motion communicated is the other; the mechanical power is

the compound of both. We can only measure the weight of any body or mass of matter by its relation to some other weight with which we are acquainted; hence we say, the weight is equal to so many pounds, or so many cubic feet of water. In like manner, we measure the velocity or intensity of the motion, by stating the height or perpendicular distance from the earth, (measured by relation to some known distance, as a foot or a yard,) through which height the weight is raised in some known space of time, as a second or a minute.

For instance, 528 cubic feet of water is a known weight or mass of water: let a machine operate upon this, and raise it upwards, through the space of one foot in the time of one minute; then $528 \times 1 \times 1 = 528$ is the number which represents the power which the machine exerts. Suppose another machine to operate on 132 cubic feet of water, and raise it four feet in one minute, then using the same measures to determine the quantities of weight, height, and time, we say $132 \times 4 \times 1 = 528$; hence these two machines are equal in the power which they exert; for in all cases the weight raised is to be multiplied by the height to which it can be raised in a given time, and the product is the measure of the power expended in raising it; consequently, all those powers are equal whose products made, by such multiplication, are equal; for example, take two powers, if one can in any given time raise twice the weight to the same height, or the same weight to twice the height, in the same time that the other power can, the first power is double the second; or, if one power can raise half the weight to double the height, or double the weight to half the height, in the same time that another can, those two powers are equal: but note, all this is to be understood only in cases of slow or equable motion of the body raised, for in quick, accelerated, or retarded motions, the *vis inertiae* of the matter moved will make a variation.

The machines actuated by the impulse of flowing water are, the undershot water-wheel, horizontal wheels, and Dr. Barker's mill. It is a common expression to call all wheels in which the water runs or shoots under the wheel, undershot; but in this place we shall only speak of

Undershot Water-Wheels, acting by the Impulse of flowing Water.—These are the most ancient and original forms of water-machines, although if they had been invented from the result of reasoning, such as we have given, they would have been the last, because their manner of action is less obvious; but this was not the case. The first machines were wheels placed in a river or running stream, and provided with vanes or wings on the circumference, called floats; the floats at the lower part of the wheel, dipped into the stream to intercept the water. When the plane of the floats became perpendicular to the direction of the current, or nearly so, they would resist or oppose the motion of the water, and the wheel would obtain motion from it in proportion to the quantity of motion, its floats abstracted from the water of the stream. The power thus obtained would be found to be only a small proportion of the power of the stream, because the water would easily escape sideways from the floats, particularly if it were attempted to take away any considerable share of the velocity of the water, by resisting or loading the wheel, so as to make it move slowly. Hence it became an obvious improvement to contract the river to the exact size of the float-boards of the wheel, or to make a close channel in which the wheel exactly fits. The next improvement would be to intercept the river or stream of water by a dam, or obstacle, in order to make it pen up, or accumulate, till it had risen to the greatest height which could be obtained, and to let the water out of the dam or

reservoir into the channel or wheel-course, through a vertical aperture or door, level with the bottom of the wheel-course; in this way, the water would be urged by the pressure of the water in the dam, and would rush out from the aperture in a stream or spout, with a velocity proportioned to the perpendicular pressure, and would strike the float-boards of the wheel so as to urge them forwards. Such is the form of the undershot wheels still generally employed in France and on the continent; but in England they have been long superseded by more effectual applications of the power of the water, and it is very rarely we meet with an undershot wheel acting by the impulse of the water. They are called ground-shot wheels, because the water runs or shoots along the ground or floor of the channels in which the wheels work.

It was first proved by Mr. Smeaton, in 1754, that only a portion of the power of any fall of water could be obtained by means of an undershot wheel; for M. Belidor had not long before stated the undershot wheel as the best mode of applying a fall of water. It was one of the continual occupations of Mr. Smeaton, during forty years, to improve the old water-mills, by substituting breast-wheels for undershot; and the advantages were uniformly so great, that these mills were copied by others, until scarcely any of the original construction remained. We do not mean that Mr. Smeaton invented the breast-wheel, for it is described by Leopold; but he first investigated its comparative advantages.

It is from this circumstance that we find, in all the mechanical writings of foreign authors, much more mathematical investigation relative to the undershot water-wheels than the importance of the subject deserves, and we shall dismiss it more briefly.

The excellent paper by Mr. Smeaton, in the Philosophical Transactions for 1759, contains a numerous list of experiments most judiciously contrived by him, and executed with the accuracy and attention to the most important circumstances which are to be observed in all that gentleman's performances.

Mr. Smeaton's rules were originally deduced from experiments made on working models, which are the best means of obtaining the outlines in mechanical enquiries; but in every case it is necessary to distinguish the circumstances in which a model differs from a machine at large, otherwise a model is more apt to lead from truth than towards it; and we must not, without great caution, transfer the results of such experiments to large works. But we may safely transfer the laws of variation, which result from a variation of circumstances, although we must not adopt the absolute quantities of the variations themselves. Mr. Smeaton was fully aware of the limitations to which conclusions drawn from experiments on models are subject, and has made the applications with his usual sagacity. The best structure of machines cannot be fully ascertained but by making trials with them, when made of their proper size.

Mr. Smeaton's Principles for Undershot Wheels.—In comparing the effect produced by water-wheels with the powers producing them; or, in other words, to know what part of the original power is necessarily lost in the application, we must previously know how much of the power is spent in overcoming the friction of the machinery, and the resistance of the air; also, what is the real velocity of the water at the instant it strikes the wheel; and the real quantity of water expended in a given time.

The velocity Mr. Smeaton measured in a most satisfactory manner in every experiment, by applying a cord and weight to the axle of the wheel, not to wind up the weight by the

motion of the wheel, but that the weight by descending should turn the wheel. He applied so much weight as would make the wheel turn, and make its floats move with the velocity which he desired or expected the effluent water to have; and this weight he adjusted until he found, by repeated trials, that the wheel moved just at the same rate, whether the water was suffered to flow and strike its floats, or whether the water was stopped, which proved that the floats of the wheel moved with precisely the same velocity as the effluent water; then by measuring the circumference of the wheel, and counting the number of turns it made in a minute, he obtained the measure of the velocity.

From the velocity of the water at the instant that it strikes the wheel, the height of head productive of such velocity can be deduced from acknowledged and experimented principles of hydrostatics; so that by multiplying the quantity or weight of water really expended in a given time by the height of a head so obtained, which must be considered as the effective height from which that weight of water had descended in that given time, we shall have a product equal to the original power of the water, and clear of all uncertainty that would arise from the friction of the water in passing small apertures, and from all doubts arising from the different measure of spouting waters, assigned by different authors.

On the other hand, the sum of the weights raised by the action of this water, and of the weight required to overcome the friction and resistance of the machine, multiplied by the height to which the weight can be raised in the time given, the product will be equal to the effect of that power; and the proportion of the two products will be the proportion of the power to the effect: so that by loading the wheel with different weights successively, we shall be able to determine at what particular load and velocity of the wheel the effect is a maximum.

From experiments conducted in this manner, Mr. Smeaton settled the following maxims:

Maxim 1. That the virtual or effective head of water, and consequently its effluent velocity being the same, the mechanical effect produced by a wheel actuated by this water will be nearly in proportion to the quantity of water expended.

Note. The virtual or effective head of any water which is moving with a certain velocity, is that height from which a heavy body must fall in order to acquire the same velocity.

The height of the virtual head, therefore, may be easily determined from the velocity of the water; for the heights are as the square of the velocities; and the velocities, consequently, as the square roots of the heights. Mr. Smeaton observed the velocity of the effluent water in all his experiments, and thence calculated the virtual head; he states that the virtual head bears no proportion to the real head or depth of water; but that when either the aperture is greater, or when the velocity of the water issuing therefrom less, they approach nearer to a coincidence; and consequently, in the large openings of mills and sluices, where great quantities of water are discharged from moderate heads, the actual head of water, and the virtual head, as determined by theory from the velocity, will nearly agree.

For example of the application of his first maxim. Suppose a mill driven by a fall of water, whose virtual head is 5 feet, and which discharged 550 cubic feet of water per minute; and that it is capable of grinding four bushels of wheat in an hour. Now another mill, having the same virtual head, but which discharges 1100 cubic feet of water per minute, will grind eight bushels of corn in an hour.

Maxim 2. That the expence of water being the same, the effect produced by an undershot wheel will be nearly in pro-

portion to the height of the virtual or effective head. This is proved in the preceding example.

Maxim 3. That the quantity of water expended being the same, the effect will be nearly as the square of the velocity of the water; that is, if a mill driven by a certain quantity of water, moving with the velocity of 18 feet per second, is capable of grinding 4 bushels of corn in an hour, another mill, driven by the same quantity of water, but moving with the velocity of $22\frac{1}{2}$ feet per second, will grind nearly 7 bushels of corn in an hour; because the square of 18 is 324, and the square of $22\frac{1}{2}$ is 506 $\frac{1}{4}$. Now say, as 324 is to 4 bushels, so is 506 $\frac{1}{4}$ to 6 $\frac{1}{4}$ bushels; that is, as 4 to 6 $\frac{1}{4}$.

Maxim 4. The aperture through which the water issues being the same, the effect will be nearly as the cube of the velocity of the water issuing; that is, if a mill driven by water rushing through a certain aperture with the velocity of 18 feet per second will grind 4 bushels of corn in an hour, another mill, driven by water moving through the same aperture, but with the velocity of $22\frac{1}{2}$ feet per second, will grind 51 bushels; for the cube of 18 is 5832, and the cube of $22\frac{1}{2}$ is 11390 $\frac{3}{4}$; then, as 5832 is to 4, so is 11390 $\frac{3}{4}$ to 7 $\frac{3}{4}$.

Maxim 5. The proportions between the power of the water expended, and the effect produced by the wheel, was 3 to 1. Upon comparing several experiments, Mr. Smeaton fixed the proportions between them for large works; that is, if the weight of the water which is expended in any given time be multiplied by the height of the fall, and if the weight raised be also multiplied by the height through which it is raised, the first of these two products will be three times that of the second.

Maxim 6. The best general proportions of velocities between the water and the floats of the wheels will be that of 5 to 2; for instance, if the water when it strikes the wheel moves with a velocity of eighteen feet per second, the wheel must be so loaded that its float-boards will move with a velocity of 7.2 feet per second, and the wheel will then derive the greatest power from the water, because as 5 to 18, so is 2 to 7.2.

Maxim 7. There is no certain ratio between the load that the wheel will carry when producing its maximum of effect, and the load that will totally stop it; but it approaches nearest to the ratio of 4 to 3, whenever the power exerted by the wheel is greatest, whether it arises from an increase of the velocity, or from an increased quantity of water; and this proportion seems to be the most applicable to large works. But when we know the effect a wheel ought to produce, and the velocity it ought to move with whilst producing that effect, the exact knowledge of the greatest load it will bear is of very little consequence in practice.

Maxim 8. The load that the wheel ought to have, in order to work to the most advantage, can be always assigned thus: ascertain the power of the whole body of water, by multiplying the weight of the water expended in a minute by the height of the fall, take one-third of the product, and it gives the effect of power which the wheel ought to produce: to find the load, we must divide this product by the velocity which the wheel should have, and that, as we have before settled, should be two-fifths of the velocity with which the water moves when it strikes the wheel.

The wheel must not be placed in an open river to be actuated by the natural current, in which case, after it has communicated its impulse to the float, it has room on all sides to escape: this is the supposititious case on which most mathematicians have proceeded; but in all these experi-

ments, the wheel is placed in a conduit or race, to which the float-boards are exactly adapted, and the water cannot otherwise escape than by moving along with the wheel. It is observable in a wheel working in this manner, that as soon as the water meets the float, it receives a sudden check, and rises up against the float, like a wave against a fixed object, inasmuch that when the sheet of water is not a quarter of an inch thick before it meets the float, this sheet will act upon the whole surface of a float, whose height is three inches; and consequently, where the float is no higher than the thickness of the sheet of water, as theory also supposes, a great part of the force would have been lost by the water dashing over the float.

The wheel which Mr. Smeaton used had originally twenty-four floats, and was afterwards reduced to twelve, which caused a diminution in the effect, on account of a greater quantity of water escaping between the floats and the floor of the channel in which it moved; but a circular sweep being adapted thereto, of such a length, that one float entered the curve before the preceding one quitted it, the effect came so near to the former as not to give hopes of advancing it, by increasing the number of floats beyond twenty-four in this particular wheel.

Mr. Smeaton observes that, in many of the experiments, the results were by different ratios than those which his maxims supposed; but as the deviations were never very considerable, the greatest being about one-eighth of the quantities in question, and as it is not practicable to make experiments of so compound a nature with absolute precision, he supposes, that the lesser powers are attended with some friction or work under some disadvantages, which have not been duly accounted for; and, therefore, he concludes that these maxims will hold very nearly, when applied to works in large.

Application of these Principles to Practice.—The first thing to be done in a situation where an undershot wheel is intended to be fixed, is to consider whether the water can run off clear from the wheel, so as to have no back water to impede its motion; and whether the fall which can be obtained by constructing a proper dam to pen up the water and sluice for it to pass through, will cause it to strike the float-boards of the wheel with a sufficient velocity to impel them forcibly forwards; and also, whether the quantity of the supply will be sufficient to keep a wheel at work for a certain number of hours each day.

When we have ascertained the height of the fall of water, that is, the height of the surface above the centre of the opening of the sluice, we must find what will be the continual velocity of the water issuing out from such opening.

In some cases, we have the velocity of the water given when it issues from the opening of the sluice, and we then require to know what height of column will produce that velocity. These two things we may find by a single rule, and an easy arithmetical operation, which is as follows:

1st. The perpendicular height of the fall of water being given in feet and decimals of feet, the velocity that the water will acquire *per second*, expressed in feet and decimals, may be found by the following rule:

Multiply the constant number 64.2882 by the given height, and the square root of the product is the velocity required.

Example 1.—If the height is two feet, the velocity will be found 11.34 feet *per second*.

Example 2.—If the height is 16,0913 feet, the velocity will be 32,1826 feet *per second*.

Example 3.—If the height is fifty feet, the velocity will be 56,68 feet *per second*.

Note. The velocities thus obtained will be only the theoretic velocity, that is, the velocity any body would acquire by falling through such height *in vacuo*, the velocity in reality will be less, generally six or seven-tenths.

The uniform velocity of a fluid being given, expressed in feet and decimals of feet *per second*, the height of the column or fall to produce such a velocity may be found by the following rule:

Multiply the given velocity into itself, and divide the product by 64,2882; the quotient will be the height required, expressed in feet and decimals.

Example 1.—If the velocity given is three feet *per second*, the height will be 0.139 of a foot.

Example 2.—If the velocity given is 32,1826 feet *per second*, the height will be found 16,0913 feet.

Example 3.—Let the velocity be 100 feet *per second*, the height will be 155,649 feet.

The knowledge of the foregoing particulars is absolutely necessary for constructing an undershot water-wheel; but the most advantageous method of setting it to work, and to find out the utmost it could perform, would be very difficult, if we were not furnished with the maximum which Mr. Smeaton settled, by shewing, that an undershot water-wheel will act to the greatest advantage, when the velocity of its float-boards is equal to two-fifths or four-tenth parts of that of the water which gives it motion.

To illustrate this, let us consider a wheel equally balanced on all sides, and turning freely round upon its pivots, its circumference would soon move as fast as the current it was placed in. Suppose the water to move at the rate of three feet in a second, the circumference of the wheel would pass through three feet in a second. In this case, the wheel performs no work, and the effect produced is nothing.

Now in attempting to apply the power of this wheel to turn any kind of machinery, suppose the work to be so proportioned, that the resistance would cause the wheel to stand still and stop the water, or make it run over the floats, in consequence of its not having sufficient force to carry the float-boards along with it. In this case also, there being no motion, there could be no mechanical effect produced; but if the resistance be diminished by degrees, the wheel would begin to partake of the motion of the current of water, and being loaded, would produce a mechanical effect proportioned to the load and velocity. The wheel would increase in its velocity in proportion as the resistance was diminished, and the mechanical effect would increase also until a certain point when the wheel moved so fast, that the water would not strike the float-boards quick enough to produce the greatest effect: this is found to be as before mentioned, when the floats move four-tenths as fast as the water, because then six-tenths of the water is employed in driving the wheel with a force proportional to the square of its velocity.

If we multiply the surface or area of the opening by the height of the column, we shall ascertain the body or column of water which should press against that float-board, which is immediately under the wheel, supposing it has no motion; but it will be found, that a small proportion of the weight of the original column hung on the opposite side of the wheel, would arrest its motion entirely; but when we would have it to move with a proper velocity, that is, two-fifths of that velocity with which the water moves, $\frac{16}{25}$ of the weight of the original column, is the weight which the wheel would raise with four-tenths of the velocity that the water moves with, and the power which the wheel would exert on the machinery to grind corn, lift hammers, raise

water, &c. is $\frac{1}{1000}$ of the weight of the water multiplied by $\frac{1}{100}$ of its velocity.

Thus it appears that an undershot water-wheel, constructed after the foregoing manner, would only raise one-third part of the water expended to the same height, as the original head or level. This is the utmost that can be expected, though often less is done; because here we suppose every part exactly performed, and the water applied to the wheel in the best manner; therefore, as we cannot come up to the maximum, we must come as near it as we can by losing the least possible of the power's impulse.

It is no advantage to have a very great number of float-boards round the wheel, because when they are struck by the water, as applied in the best manner possible, the sum of the impulses exerted on the different floats, will but be equal to the impulse made against one float-board struck by all the water issuing from the sluice at right angles to its surface. But as this float-board must move forward, there must be a succession of float-boards to receive the impulse of the water, and since they cannot receive it at right angles, there will be some loss of impulse in that succession. Besides when the first float-board is so far past the perpendicular, as to have the action of the water intercepted by the succeeding one, it is checked by the back water through which it must pass in rising out of the water, and thereby be so far retarded as to take from the full effect of the impulse on the following float. Indeed if all the water could run off immediately after having performed its office, this would not happen; but it can seldom be effected in undershot-mills, especially those built upon rivers. All the remedy in such case is, (when the diameter of the wheel is settled) to fix just such a number of floats upon it, that each one, after it has received the full impulse of the water, may come out of the water as soon as possible, that another succeeding float may be brought to receive the impulse, otherwise the wheel would remain a moment without any impulse.

In the article *MILL* we have given a table for the dimensions and proportions for undershot wheels, which was calculated by Mr. Ferguson. Dr. Brewster, in his new edition of Mr. Ferguson's works, has given an improved table, which is calculated upon the following principles.

It is evident that the water-wheel must always move with less velocity than the water, even when there is no work to be performed; for a part of the impelling power is necessarily spent in overcoming the *inertia* of the wheel itself; and if the wheel has little or no velocity, it is equally manifest that it will produce a very small effect.

There is consequently a certain proportion between the velocity of the water and the wheel, when the effect is a maximum. Mr. Smeaton has shewn the greatest effect is produced when the velocity of the wheel is between one-third and one-half, but the maximum is much nearer to one-half than one-third. He observes also that one-half would be the true maximum, if nothing were lost by the resistance of the air, the scattering of the water carried up by the wheel, and thrown off by the centrifugal force, and the leakages of the water between the floats and the water-course, all which tend to produce a greater diminution of the effect at that velocity, which would be the maximum if these losses did not take place, than they do when the motion is a little slower. The great hydraulic machine at Marly, the wheels of which are undershot, was found to produce a maximum effect when the velocity of the wheel was two-fifths that of the current. Hence Dr. Brewster concludes that in theory the velocity of the wheel is one-half that of the current, and that

in practice it is never more than three-eighths of the stream's velocity, when the effect is a maximum.

Dr. Brewster's Table of undershot Water-Wheels, in which the velocity of the wheel is three-sevenths of the velocity of the water, and the effects of friction on the velocity of the stream are reduced to computation. The wheel is supposed to be fifteen feet diameter.

Height of the Fall of Water.	Velocity of the Water per Second, Friction being considered.	Velocity of the Wheel per Second being three-sevenths that of the Water.	Revolutions of the Wheel per Minute, its Diameter being fifteen Feet.
Feet.	Feet and Decimals.	Feet and Decimals.	Revolutions and Decimals.
1	7.62	3.27	4.16
2	10.77	4.62	5.88
3	13.20	5.66	7.20
4	15.24	6.53	8.32
5	17.04	7.30	9.28
6	18.67	8.00	10.19
7	20.15	8.64	10.99
8	21.56	9.24	11.76
9	22.86	9.80	12.47
10	24.10	10.33	13.15
11	25.27	10.83	13.79
12	26.40	11.31	14.40
13	27.47	11.77	14.99
14	28.51	12.22	15.56
15	29.52	12.65	16.13
16	30.48	13.06	16.63
17	31.42	13.46	17.14
18	32.33	13.86	17.65
19	33.22	14.24	18.13
20	34.17	14.64	18.64

Another Manner of applying Water to an undershot Wheel.—This was proposed by M. Fabre as the result of much mathematical investigation, and has been so frequently recommended by authors of eminence, that we shall give a short description without entering into all his rules for the proportions. The principal difference in this wheel from that in common use is, that the water is made to run down a rapid slope or inclined plane, in order to strike the floats of the wheel, instead of issuing from an aperture or sluice situated beneath the surface of the water in the reservoir. A mill is usually situated at a distance from the river, with a canal or water-course to conduct the water to the mill; as it is of the highest importance to have the height of the fall as great as possible, the bottom of the canal or water-course, which conducts the water from the river to the mill, should have a very small declivity; for the height of the water-fall at the mill will diminish in proportion as the declivity of the canal is increased: it will be sufficient to make it slope about one inch in 200 yards, taking care to make the declivity about half an inch in the first 48 yards, in order that the water may have a velocity sufficient to prevent it from flowing back into the river.

When the water is thus brought to the channel in which the wheel is placed, the water is recommended to be conducted down a slope or inclined plane, making an angle of $64\frac{1}{2}$ degrees with the horizon; that is, in a perpendicular of ten feet, the slope should deviate from it $4\frac{1}{2}$ feet: at the bottom of this slope the water is to be again conducted horizontally, and then to strike the float-boards of the

wheel. To render the fall of the water easy, the slope is to be rounded off by a convexity at top and a concavity at bottom, to lead the water from the horizontal to the slope, and again from the slope without abruptness. It is supposed that the water, in running down this inclined plane, will acquire the same velocity as if it had fallen perpendicularly through a height equal to the perpendicular height of the slope.

The distance through which the water runs horizontally, from the foot of the slope before it acts upon the wheel, should not be less than two or three feet, in order that the different portions of the fluid may have obtained an horizontal direction; but if this horizontal distance be much larger, the velocity of the stream would be diminished by its friction on the bottom and sides of the water-course. That less water may escape between float-boards and the bottom of the course, it should be formed into the arch of a circle concentric with the wheel, which sweep should be prolonged, so as to support the water as long as it can act upon the float-boards; beyond this sweep should be a step or fall of not much less than nine inches with a slope of about 45 degrees, that the water having spent the greater part of its force in impelling the float-boards, may not accumulate below the wheel and retard its motion. After this step the course of discharge, or tail water-course to run off the water from the wheel, should be floored with wood or masonry about 16 yards long, having an inch of declivity in every two yards.

The canal which conducts the water from the course of discharge to join the river again, should slope about four inches in the first 200 yards, and three inches in the second 200 yards, and so decreasing gradually till it terminates in the river. But if the river to which the water is conveyed, should be subject to be swollen by the rains, so as to force the water back upon the wheel, the canal must have a greater declivity, in order to prevent this from taking place. Hence it will be evident, that very accurate levelling is necessary for the proper formation of the mill-course. The tail water-course ought always to have a very considerable breadth, which should be greater than that of the wheel-race, or part in which the wheel acts, that the water having room to spread may have less depth. The section of the fluid at the point where it strikes the wheel should be rectangular, the breadth of the stream having a determinate relation to its depth. If there is a great stream of water, the breadth should be triple the depth; if there is a moderate quantity, the breadth should be double the depth; and if there is very little water, the breadth and the depth should be equal. The depth of the water here alluded to is its natural depth, or that which it would have, if it did not meet the float-boards. The effective depth is generally two and a half times the natural depth, and is occasioned by the impulse of the water on the float-boards, which forces it to swell, and increases its action upon the wheel.

As it is of great consequence that none of the water should escape, either below the float-boards or at their sides, without contributing to turn the wheel, the breadth of the float-boards should be wider than the sheet of water which strikes them. The diameter of the water-wheel should be as great as possible, unless some particular circumstances in the construction prevent it; but ought never to be less than seven times the natural depth of the stream or thickness of the sheet of water, where it meets the float-boards. The wheel will move irregularly, sometimes quick and sometimes slow, according to the position of the floats with respect to the stream; unless the number of float-boards is considerable, the wheel must have so many floats, that

two floats will at least be always in the circular sweep at the bottom of the wheel; but in order to remove any inequality of motion in the wheel, and prevent the water from escaping beneath the tips of the float-boards, it should have as many float-boards as possible, without loading it, or weakening the rim on which they are placed. The float-boards should not be perpendicular to the rim, or, in other words, a continuation of the radius, but should be inclined to the radius; the water will thus heap upon the float-boards, and act not only by its impulse, but also by its weight. When the velocity of the stream is eleven feet *per* second, or above this, the inclination should never be less than thirty degrees; or when this velocity is less, the inclination should diminish in proportion; so that when it is four feet, or under, the inclination should be nothing, that is, the float-boards should point to the centre of the wheel.

It is a strong practical objection to this manner of applying the water to the wheel, that when the water of the river sinks in dry weather from a deficiency of water, it would not run over the top of the fall, and the mill could not work at all even if it sunk only ten or twelve inches: in like manner, when the water rises in floods, the water at the top of the fall would become so deep, as to require some shuttle to prevent it from inundating the wheels, at the same time that the stagnant water in the mill-race would prevent the wheel from working. Almost all rivers are subject to floods, and often they rise and fall, three, four, six, and eight feet above their ordinary level in fair weather; now the water mostly rises at the tail or discharge of the water as much as the head, and the wheel-race will therefore be full of stagnant water, which is called tail-water, and obstructs the motion of the wheel.

In a ground-shot wheel, where the water issues from a shuttle on a level with the bottom of the wheel-race, it can always work in dry seasons, as long as the river contains any water, although the power diminishes almost to nothing, when the water sinks low, and will not rush out with force from the shuttle. In floods of water, this wheel has a greater advantage, because the depth of head which urges the flowing water is increased when the water is high, and this makes it drive the tail-water forcibly out of the wheel-race, and enable the wheel to work, when a wheel with an inclined fall would infallibly be stopped.

Breast-wheels and overshot-wheels, properly constructed, have still greater advantages, in clearing themselves from tail-water, and this is a very important object.

Floating-Mill with undershot Wheels.—A large floating water-mill, to be worked by the tides or currents, was stationed some years ago in the river Thames, between London and Blackfriars bridge, by permission of the Board of Navigation. Such permission having been granted with the view of reducing, if possible, the price of flour in the metropolis, and contributing to a constant supply of that necessary article of subsistence. The simplicity of this invention renders a long description superfluous, as it consists in merely applying the force of two large undershot water-wheels on each side of a barge, or any other vessel calculated to contain the interior part of the machinery; the float-boards are disposed in a proper manner to be acted on by the tide or current, so as to give the wheels a rotatory motion, and by connecting them with proper machinery, to answer the purposes for which the mill is intended.

Any ship, brig, sloop, or other vessel, may be used for this purpose, provided it is of sufficient size to accommodate the works to be erected, yet in point of expence it will be better to employ such as are rendered unfit for sea-service.

When it is intended that the ship or mill should be stationary, it must be anchored, moored, or otherwise made fast, so as to swing with the tide when necessary; but the mill may be worked while the vessel in which it is erected is sailing, when wind and other circumstances permit.

The number and size of the water-wheels to be used may be varied, according to the size of the ship or vessel, or to the strength of the tide or current, and the power required; and the wheels may be constructed as in common undershot mills, or with folding-floats, for the more readily freeing them from the water: two wheels are to be placed vertically, on an horizontal axis, of such length, that, the axis being placed across the ship or vessel, one wheel may run on each side of it on the same axis.

A mill constructed in the manner above described may be moved by the strength of from two to six large water-wheels, or such other number as the ship or vessel will accommodate. These water-wheels may dip into the water from three to four, or more feet deep; they should be so connected together as to be easily engaged with and disengaged from each other, so that during the weak part of the tide they may all be made to act on one pair of mill-stones, if necessary; and as the strength of the tide increases, more stones or other machinery may be put in motion, so as at all times to do business in proportion thereto.

In a mill of this kind the water-wheels do not admit of having water-courses, or any equivalent contrivances, to conduct the water to the wheels, as in other undershot wheels; but the float-boards must be large enough to receive the power required from merely dipping into the current of the tide-water.

The vessel of the mill in the Thames is the hull of an old ship of two or three hundred tons burthen, which being moored in the river by chains, so that it can swing round when the tide changes, the wheels will always turn the same way round; one water-wheel is fixed on each side of the vessel, a long iron axis being common to both; the extreme ends of the axis are supported in a frame-work of timber, and another very strong frame of timber is fixed outside of the wheels at the level of the water, which floats in the water, and is only attached to the mill by chains; this is to protect the wheels from injury, by vessels which pass and repass. Each water-wheel is 18 feet diameter, and 14 feet broad; the float-boards are each 3 feet deep, and are about sixteen in number, affixed on the circumference of cast iron-wheels, or circles, which are 12 feet diameter, there are three of these circles for each wheel; hence we find each float-board exposes a surface of 42 square feet to the action of the current, and if we suppose each wheel to have two floats in action at the same time, the power of the mill will be derived from 168 square feet acted upon by the water, which seldom exceeds a velocity of four miles *per* hour, or 352 feet *per* minute.

The iron axis of the water-wheels is a hollow tube of nine inches diameter outside, and five inches within, made in four lengths of 12 feet each, properly joined together, and extending across the vessel from one wheel to the other. On the middle of this axis a large wheel of 11 feet diameter is fixed, and surrounded by a brake or gripe like that used in a wind-mill, the use of which is to stop the mill when it requires repairing. Near to this brake-wheel is a large bevelled cog-wheel 13 feet diameter, with 89 cogs, which gives motion to a bevelled pinion two feet eight inches diameter, with eighteen cogs fixed on the top of a vertical axis. On this axis is also a large horizontal spur-wheel 12 feet diameter, with 201 cogs, which gives motion to pinions of one foot diameter, and 17 cogs fixed on the spindles of the mill-

stones. There are four pair of mill-stones, two pair of 4½ feet and two pair of 3½ feet diameter, and the mill also works a dressing-machine for the flour. The mill-stones make 57½ revolutions for one revolution of the water-wheels, which move very slow, scarcely two turns *per* minute, in the most favourable periods of the tide. The circumference of each taken through the middle of the float-boards is 47 feet; hence the float-boards move about 94 feet *per* minute, when the mill-stones make their proper number of revolutions to grind with the greatest effect.

It was found that on a flood-tide, this mill would drive two pair of 3½ feet mill-stones, and a flour dressing-machine, but on the ebb-tide only one pair of 4-feet stones and the machine; thus it is only the performance of a small mill, although the wheels are of large dimensions, and it would require enormous wheels to make an effective floating mill in the river Thames.

This machine is now removed from the river, because it was found to do so much injury to the vessels which continually ran against its floating frame, and the repairs of the damages frequently done to the mill by ice and the craft took away all the advantages of the mill.

Undershot Wheels with oblique Floats.—Attempts have been made to construct water-wheels for tide-rivers which receive the impulse obliquely, like the sails of a common wind-mill. This would in many situations be a great advantage. A very slow but deep river could in this manner be made to drive mills; and although much power would be lost by the obliquity of the impulse, the remainder might be very great. Dr. Robinson speaks of a wheel of this kind which was very powerful; it was a long cylindrical frame, having a plate standing out from it about a foot broad, and surrounding it with a very oblique spiral like a cork-screw. This was immersed about one-fourth of its diameter (which was nearly 12 feet), having its axis in the direction of the stream. By the work which it was performing, it seemed more powerful than a common wheel which occupied the same breadth of the river. Its length was not less than 20 feet; had it been twice as much it would have been nearly redoubled in its power without occupying more of the water-way. It is probable such a spiral continued quite to the axis, and moving in a hollow canal wholly filled by the stream, might be a very advantageous way of employing a deep and slow current.

In the Transactions of the Society of Arts, vol. xix. a water-wheel is described, in which the float-boards are placed obliquely to the axis of the water-wheel at about an angle of 40 degrees, being fixed to the rim in pairs, which are inclined equally to the axis of the wheel, but in opposite directions to each other; so that the two float-boards of each pair point towards each other in an angle of about 80 degrees, and if the pair of floats were continued they would meet in the middle of the breadth of the wheel. The water is made to strike the floats within this angle, and in consequence all the water which is emitted by the sluice and strikes upon the oblique floats will be reflected from the sides or ends of the two pair of float-boards towards the vertex of the angle, which they make; but the pair of floats do not touch each other, so that the vertex of the angle is open; but to prevent the water passing freely through the open angle, one of the float-boards is made to extend far beyond the vertex, or point, where they would intersect, and the other is made to fall short of it, nevertheless the water would certainly pass through the opening. It is stated, that the motion of the ordinary wheel with parallel floats is greatly retarded by the resistance which they experience in rising up or quitting the tail-water of the stream, from the

pressure of the atmosphere on their upper surface before the air gets admission beneath the floats; but in Besant's wheel this resistance is greatly diminished, as the floats emerge from the stream in an oblique direction. The water-wheel is constructed in the form of a hollow drum, so as to resist the admission of the water. Although this wheel is much heavier than those of the common construction, yet it revolves more easily upon its axis, as the stream has a tendency to make it float. We cannot recommend this wheel, but on the contrary think it one of the worst forms, as it tends to increase that loss which arises in all undershot-wheels from the change of figure which the water must undergo when it strikes the float, and we should not have mentioned it, but that it has been so frequently copied and recommended by different authors.

Horizontal Water-wheels actuated by the Impulse of Water.—These have been considerably in use on the continent, and deserve our notice from the simplicity of their construction. The wheel is constructed in the same manner as an undershot-wheel, having float-boards fixed round its circumference in the form of radii; it is mounted on a vertical axis, the upper end of which is fixed to the spindle of the mill-stone, if the mill is intended to grind corn; but in some cases, it is better to fix a cog-wheel on the upper part of the vertical axis with teeth round its edge, to give motion to trundles or pinions on the spindles of the mill-stones, because the floats of the wheel must always be made to move with a given proportion of the velocity of the water. The wheel-race or water-course may be made nearly the same as for an undershot-wheel, if we suppose it laid down in an horizontal position; that is, a trough or channel of masonry is constructed in which the wheel works, and the float-boards of the wheel are exactly fitted to it: at one end of this channel is the aperture or sluice through which the stream of water issues, and strikes the floats of the wheel so as to turn it round, and the water passes forwards and escapes at the other end of the channel. When the water is delivered upon the wheel in an horizontal direction, or perpendicular to its axis, the float-boards should be inclined about twenty-five degrees to the plane of the wheel, and the same number of degrees to the radius, so that the lowest and outermost sides of the float-boards may be farthest up the stream and be met by the water first.

In many cases, the water-course is made inclined to the plane of the wheel in such a degree, that the water may strike the float-boards perpendicular to their surfaces.

In the southern provinces of France, where horizontal water-wheels are generally employed, the float-boards are made of a curvilinear form so as to be concave towards the stream; they are generally segments of spheres, or hollow wooden bowls or ladles fixed on the rim of the wheel: the water, in this case, is conducted through a pipe, and projected in a jet on a direction a little inclined to the horizon. When the height of water is very considerable, this is, perhaps, the best form for the floats, or ladles, as they are called.

The chevalier de Borda observes, that in theory a double effect is produced when the float-boards are concave, but that the effect is diminished in practice, from the difficulty of making the fluid enter, and leave the curve in a proper direction. Notwithstanding this difficulty, however, and other defects which might be pointed out, horizontal wheels with concave float-boards are always superior to those in which the float-boards have plane surfaces.

Mr. Smeaton constructed a small corn-mill with a horizontal water-wheel, of which the following are the principal dimensions. Fall of water $52\frac{1}{2}$ feet; diameter, or

bore of the nose-pipe through which the water issued in a jet to strike upon the wheel, $1\frac{1}{2}$ inch; diameter of the water-wheel 10 feet to the centre of the floats or ladles, which were twelve in number; they were made of a concave form, nearly segments of spheres, and about 14 inches in diameter; and fixed round the circumference of the wheel, so that the planes of the circular rims, or edges of the hollow ladles, were not perpendicular to the plane of the wheel, but inclined thereto in such a degree, that the jet of water issuing from the nose-pipe at an angle of 22 degrees from the horizontal line, would strike the floats in the centre and perpendicular to the circular edge of the hollow; the internal surface of the floats being really spherical, the water would always strike perpendicularly into the concavity of the bowl. The water-wheel axis rose up perpendicularly into the mill-house, and on the top a wheel of 4 feet 8 inches in diameter, and 44 cogs, was fixed for giving motion to the pinions on the axis of the mill-stones. The largest pinion of 17 cogs was fixed on the axis of a pair of stones 4 feet 6 inches in diameter, and the smaller pinion of 13 cogs on the axis of a stone 3 feet 6 inches in diameter. It was not intended to turn both these pairs of stones at the same time, but it was necessary to have two pairs for different uses.

When this mill moved with a proper velocity to grind to the greatest advantage, if the 4 feet 6 inches stones were used, the water-wheel made 25 revolutions *per* minute, and the stones therefore made 65 revolutions *per* minute, and the float-boards moved with a velocity of 784 feet *per* minute; but when turning the smaller mill-stones of 3 feet 6 inches diameter, the water-wheel went best when it made 26 revolutions, and therefore turned the mill-stone 88 turns *per* minute; and the velocity of the floats was 816 feet *per* minute.

Mr. Smeaton calculated the velocity of the water issuing from the pipe at 3403 feet *per* minute, which is the velocity due to a 50 feet fall, because he allowed the $2\frac{1}{2}$ feet to overcome friction, and the expenditure of the $1\frac{1}{2}$ inch nose-pipe at 30 cubic feet *per* minute allowing for friction. This mill ground one bushel of wheat *per* hour, on the average of a great many experiments, now $30 \times 50 = 1500$ cubic feet, falling one foot *per* minute. It is found by repeated experiments, that 600 cubic feet falling one foot *per* minute on a good water-wheel is an ample allowance for grinding a bushel of wheat, as it may be done by 530; hence this fall of water ought to have ground $2\frac{1}{2}$ bushels *per* hour instead of one. The mill, however, admits of improvement in making the floats of the wheel move quicker.

When the mill-stone of an horizontal mill is fixed on the upper end of the axis of the water-wheel, if the mill-stone be five feet in diameter, it should never make less than sixty turns in a minute, and the wheel must perform the same number of revolutions in the same time; and in order that the effect may be a maximum, or the greatest possible, the velocity of the current must be more than double that of the wheel.

Suppose the mill-stone, for example, to be 5 feet diameter, and the water-wheel 7 feet, it is evident that the mill-stone and wheel must at least revolve 60 times in a minute; and since the circumference of the wheel is 22 feet, the float-boards will move through that space in the 60th part of a minute, that is, at the rate of 22 feet *per* second; which being doubled, makes the velocity of the water 44 feet one second, answering, as appears from the rule, for the velocity of falling water, to a fall of 30 feet. But if the given fall of water be less than 30 feet, we may procure the same velocity to the mill-stone, by diminish-

ing the diameter of the wheel. If the wheel, for instance, is only 6 feet diameter, its circumference will be 18.8 feet, and its floats will move at the rate of 18.8 feet in a second, the double of which is 37.6 feet *per second*, which answers to a head of water 22 feet high. The diameter of the water-wheel, however, should never be less than 6 or 7 feet, because the float-boards change their direction so rapidly, in consequence of their proximity to the centre, that they will not receive the full action of the water, because it acts in a perpendicular direction to the float-board only for a moment. Hence there will be a certain height of the fall, beneath which the simple horizontal wheel cannot be employed; and beyond that, wheel-work must be introduced to obtain the requisite velocity for the mill-stones.

In the provinces of Guienne and Languedoc, in France, another species of horizontal wheel is employed for turning machinery. It consists of an inverted cone, with spiral float-boards of a curvilinear form winding round its surface. The wheel moves on a vertical axis in a pit or well of masonry, to which it is exactly fitted, like a coffee-mill in its box. It is driven chiefly by the impulse of the water, conveyed by a spout or canal in a stream, which strikes the oblique float-boards; and when the water has spent its impulsive force, it descends along the spiral float-boards, and continues to act by its weight till it reaches the bottom, where it is carried off by a canal. The idea of this machine is ingenious. The jet of water, being first applied to the upper or largest part of the cone, strikes the float-boards at the part where they move with the greatest velocity, in consequence of their being on the largest radius; but as the water loses its velocity, in consequence of the motion it has imparted to the wheel, it descends in the cone, and acts upon the floats lower down, where, the radius being less, the floats move more slowly, and are therefore better adapted to receive the action of the water with its diminished velocity.

M. Mannoury Desfont's horizontal Water-Wheel, which he calls Danaide.—This receives the impulse of the water in a different manner from any which we have described, and is described in a report to the Institute of France in 1813. The water-wheel is fixed in a horizontal position upon a vertical axis, and supported upon the pivots thereof, so as to be capable of turning round. It is not in reality a wheel, but a hollow cylinder or drum capable of containing water; it is open at top, and united to the axis in the centre of the circular plane, which forms the bottom. Within this drum, and concentric with it, a solid cylinder is fixed; it is of less dimensions than the drum itself, and occupies such portion of the content of the drum as to reduce the open part which can contain water to a hollow ring or circular trough, open at top, and of a considerable depth, but only a few inches in width. The depth is described as being nearly as great as the diameter of the wheel.

The water coming from an elevated reservoir, is projected in jets from one or more pipes into this annular space which surrounds the rim of the wheel. These pipes descend in an inclined direction, till they are nearly on a level with the surface of the water in the annular space; and the extremities turn horizontally, so as to project the jet horizontally, and in the direction of tangents to the mean circumference of the water contained in the annular space.

Suppose this space which surrounds the wheel is full of water, then the stream issuing from the jet causes the wheel to turn round upon its axis, because it takes hold or acts upon the water in the annular space, and tends to give the water a circulating motion within the annular space; but the

friction, or resistance, which the water would find in such circulation, causes the wheel to turn round with the water, unless the load on the wheel, or resistance to its motion, is too great.

The water which is continually thrown into the wheel escapes from the annular space by passages which proceed from the bottom thereof to the centre of the wheel; and there are openings at the centre, where the water can drop out *below*. To form the passages for this purpose, the solid cylinder which is fixed in the centre of the hollow drum is of less depth than the other, and leaves a space between the bottom of the solid and the bottom of the hollow, which is divided into compartments by diaphragms fixed upon the bottom of the trough, and proceeding like radii from the circumference to a central hole in the bottom of the trough, which is left open to allow the water to escape. The report states, that the velocity with which the water issues from the jets makes the machine move round its axis; and this motion accelerates by degrees, till the velocity of the water in the annular space equals that of the water from the reservoir, so that no sensible shock is perceived of the affluent water upon that which is contained in the machine. The motion of the wheel is regular, because the action is continual; but in the case of other water-wheels, where the water strikes against float-boards, such boards must necessarily be of a determinate number, and the motion must be given to the wheel by a succession of impulses, as the floats arrive before the stream. We might indeed suppose a wheel with an infinite number of floats, but it would then amount to a plain cylindrical or flat surface, upon which the water would not take sufficient hold to produce any sensible effort to turn it round.

Now in M. Desfont's wheel, in place of float-boards, the rim of the wheel is clothed with water, which is capable of being acted upon by the water issuing from the jets. This action tends to put the water in the annular space in motion, and to carry the wheel along with it, by the adhesion it must naturally have to the sides of the channel which contains it. The velocity of the wheel will be in proportion to the resistance that the load makes to its motion.

The circular motion of the wheel communicates a centrifugal force to the water contained in the annular cavity of its rim, which causes it to press against the outermost side of the channel. This centrifugal force acts equally upon the water contained in the compartments at the bottom of the said rim; but its action diminishes as the water approaches the centre.

The whole mass of water is then animated by two opposite forces, *viz.* gravity and the centrifugal force. The first tends to make the water run out at the hole in the bottom of the wheel at the centre, and the second to drive the water from that hole.

To these two actions are joined a third, *viz.* friction or resistance, which acts an important and singular part; and in this machine the friction of the water produces its powers of action, while in most other machines it always diminishes their powers. The effect in this machine would be nothing, were it not for the resistance which the water finds opposed to its free circulation in the annular space round the rim of the wheel.

By the combination of these three forces there ought to result a more or less rapid flow of water from the hole in the centre at the bottom of the wheel; and the slower this water issues, the greater will be the effective power of the machine for producing the useful effect for which it is destined.

The moving power in this machine, like all others, is the weight of the water which runs into the wheel, multiplied

by the elevation the reservoir has above the bottom of the wheel, or orifice from which it issues in quitting the same; but the useful mechanical effect is stated to be equal to that product, diminished by half the force which the water retains, when it flows out at the orifice below, and quits the machine.

In order to ascertain, by direct experiment, the magnitude of this effect, Messrs. Prony and Carnot fixed a cord to the axis of the machine, which passing over a pulley, raised a weight by the motion of the machine. By this means the effect was found to be $\frac{7}{8}$ ths of the power, and often approached $\frac{7}{8}$ ths, without reckoning the friction of the pulleys, which has nothing to do with the effect.

We cannot help suspecting some mistake in these experiments, or in the statement of them, but think the machine deserves a trial; and if it should produce near the result above stated, it would be a most valuable addition to our means of employing falls of water; and its simplicity would be a great recommendation, particularly for corn-mills, because the perpendicular axis is immediately adapted for that purpose, without any wheel-work.

Horizontal Mill with oblique Vanes.—In Belidor's *Architecture Hydraulique* he describes a different form of horizontal mill. The wheel is a circular rim, and the radii or arms are all oblique vanes or floats, precisely the same as the common smoke-jack. This wheel is placed horizontally in a well, to which it is exactly fitted, but the rim of the wheel does not touch the circular wall of the well. The axis of the wheel ascends upwards into the mill-house, and the spindle of the mill-stone is fixed into it. A horizontal arch-way is conducted to the well sideways, and above the part where the wheel is situated. This arch conveys the water into the well over the wheel; and beneath the wheel there is a similar horizontal arch to carry away the water, after it has passed through the wheel, that is, in the spaces between its vanes or floats. The weight of the water presses upon them in a perpendicular direction, and the planes of these floats being all inclined to the horizon, the action of the pressure tends to turn the wheel round on its axis, by the same action as the smoke upon the vanes of a jack, or like a wind-mill.

The water is supplied in such a body through the upper arch, that the well is always kept full, with a considerable depth of water pressing upon the wheel; whilst the lower arch carries away the water so freely, that it runs away from beneath the wheel as fast as it can pass through the vanes of the same.

The mill described by Belidor was at Toulouse, and contained a number of such wheels in a row, each giving motion to one pair of stones.

Horizontal Machines moved by the Reaction of Water.—The reaction of water, issuing horizontally through a spout or orifice, may be employed to communicate motion to machinery; and though this principle has not yet been adopted in practice, it appears from theory, and from some detached experiments on a small scale, that a given quantity of water, falling through a given height, will produce greater effects by its reaction than by its impulse. If we suppose a vertical pipe of any given height, open at both ends, and that water is poured into it at the top, the water will issue at the bottom of the pipe with a velocity proportioned in a certain manner to its altitude, because every particle of water which issues is pressed upon and impelled by the weight of all the particles which are above it. Now, suppose the pipe bent or curved at the bottom, so that it will turn the stream of water into a horizontal position; in this case, the pressure and force, of which we have spoken, will be deflected from the vertical direction to the horizontal. Now

it is clear that the bent part of the pipe, or some part of the interior surface of the tube opposite to the orifice, must sustain all the pressure which is thus deflected or transmitted in another direction; and if the tube is freely suspended, it will retreat before this pressure, and be put in motion. If we suppose the tube to have no resistance to motion, then it would receive all the motion of the water, which would not move at all after it issued from the orifice, but the orifice and tube would move away from the water. This is an impossible case, and in reality the motion of the effluent water will be divided between the pipe or tube and the issuing water, in proportion to the resistance with which each is loaded. Another and perhaps more familiar explanation is, that the water presses against every part of the interior part of the pipe, except against the orifice or aperture, which is open; and in consequence, the unbalanced pressure on the part opposite to the orifice will tend to put the pipe in motion. A sky-rocket mounts in the air from a similar cause.

Dr. Barker's mill by the reaction of water was the first of this kind of machines, and is described by Desaguliers, in 1743. In his *Experimental Philosophy*, vol. ii. p. 460, he calls it a machine to prove Mr. Parent's proposition experimentally, viz. that an under-shot water-mill does most work, when the water-wheel moves with only a third part of the natural velocity of the water that drives it. He says, that Dr. Barker had this thought, and communicated it to him, saying, that it would be an experimental proof of Mr. Parent's proposition; in consequence of which, Desaguliers made a working model of it, which he shewed to the Royal Society, and the experiments upon it, at their meeting in 1742.

It consists of an upright pipe or trunk, communicating with two horizontal branches, like an inverted T; thus, *L*. This perpendicular pipe is poised upon a pivot at the lower end, and the upper end is connected with the spindle of the mill-stone, or other machine to which it is to communicate motion. The top of the pipe is formed into a funnel, into which a stream of water is conducted, and runs down the pipe: the water escapes through a hole in each of the horizontal arms, which holes are near the ends of the arms, and open in opposite directions, and in such a position that they will direct the stream of water horizontally, and nearly at right angles to the length of the arms.

Suppose water to be poured in at the top of the tube from the spout, it will then run out by the holes at the ends of the arms, with a velocity corresponding with the depth of these holes beneath the surface of the water in the vertical pipe. The consequence of this must be, that the arms must be pressed backwards, for there is no solid surface at the hole on which the lateral pressure of the water can be exerted, while it acts with its full force on the inside of the tube opposite to the hole. This unbalanced pressure, acting upon the opposite sides of both arms, will make the tube and the horizontal arm revolve upon the spindle as an axis.

This will be more easily understood, if we suppose the orifices to be shut up, and consider the pressure upon a circular inch of the arm opposite to the orifice, the orifice being of the same size.

The pressure upon this circular inch will be equal to a cylinder of water, whose base is one inch in diameter, and whose altitude is the height of the fall; and the same force is exerted upon the shut-up orifice. These two pressures being equal, and acting in opposite directions, the arm will remain at rest; but as soon as the orifice is opened, the water will issue with a velocity due to the height of the fall. The pressure of the water upon the orifice will now be removed, and as the pressure upon the circular inch opposite

to the orifice still continues, the equilibrium will be destroyed, and the arm will move in a retrograde direction, unless it is withheld by some force greater than that pressure.

In the original model made by Defaguliers, the vertical tube was a cylindrical pipe, but the lower arms were of a square figure in their cross section, and the apertures through which the water issued were likewise of a rectangular figure, and provided with sliders or sluices, which were regulated by screws so as to increase or diminish the openings.

It is clear that the machine must press backwards, and there is no difficulty in understanding the intensity of this pressure, when the machine is at rest. But when it is allowed to run backwards, withdrawing itself from the pressure, the intensity of it is diminished; and if no other circumstances intervened, it might not be difficult to say what particular pressure corresponded to any rate of motion. Defaguliers affirms the pressure to be the weight of a column, which would produce a velocity of efflux equal to the difference of the velocity of the fluid and of the machine: and hence he deduces, that its performance will be the greatest possible, when its retrograde velocity is one-third of the velocity acquired by falling from the surface; in which case, it will raise $\frac{2}{3}$ ths of the water expended to the same height.

But this is not a perfect account of the operation; for the water which issues descends in the vertical trunk, and then moving along the horizontal arms, partakes of their circular motion. This excites a centrifugal force, which must be exerted against the ends of the arms by the intervention of the fluid. The whole fluid contained in the arms is subject to this action, each part in a degree proportioned to its distance from the axis, because every particle is pressed with the accumulated centrifugal forces of all the sections that are nearer to the axis. This increases the velocity of revolution, and this mutual co-operation would seem to lead to a continual acceleration in the velocity of both motions. But, on the other hand, this circular motion must be given anew to every particle of water, when it enters the horizontal arm. This can be done only by the motion already in the arm, and at its expense; neither can the perpendicular tube furnish an unlimited supply. Thus there must be a velocity which cannot be exceeded even by an unloaded machine.

Improved Form of Dr. Barker's Mill.—This consists in introducing the supply of water at the lower end of the tube, instead of the upper end. It was first proposed by M. Mathon de la Cour, in the *Journal de Physique*, 1775, and the invention was, 20 years afterwards, claimed by a Mr. Ramsey, and very recently by M. Mannoury Desot in France. This last machine is very highly recommended by Messrs. Perier, Prony, and Carnot, in a report to the Institute, from which we make the following extracts.

The water is introduced into the revolving arms at the lower part, through the axle: the pipe which brings the water encloses the pivot, upon which it turns. This water is brought to the reservoir through a curved canal, by means of which the revolving arms, and the mill which it puts in motion, are placed by the side of the reservoir, and neither above nor below it, which would much injure the working, and the simplicity of the machine. By bringing the water from below, by means of a canal, the machine is reduced to a simple water-wheel, the axis of which is fixed immediately to the moving mill-stone.

Although the water enters with little velocity into the revolving arms, it causes them to turn very fast, because

the apertures for its egress being much smaller than those for its entrance, the velocity at the entrance is reciprocally much smaller than it is at the egress. But this velocity at the egress is not an absolute motion; it is only a relative motion with respect to the tube from which it issues, otherwise there would result a spontaneous augmentation of power, which would not agree with the principles of mechanics.

The apertures for the entrance and the egress of the water being proportioned as they ought to be, in order to obtain the greatest effect; then the report states,

1. The reaction, that is, the force of pressure which acts upon the revolving arms, at each of the apertures of egress, is equal to the weight of a column of water of the same base as the aperture, and of the height of the level of water in the reservoir.

2. The velocity of the rotation of the arms measured at the same points is to the velocity due to the height of the level of the water in the reservoir, as the aperture for the entrance of the water into the mill-wheel is to the sum of the apertures of egress.

Whence it follows, by multiplying this force and this velocity, that the effect produced by the machine in a given time is equal to the weight of all the water that the reservoir can furnish during this time, by the height of the level of the water in the reservoir. Now this product, it is well known, is the utmost that can be obtained by the best hydraulic machines.

This disposition of Dr. Barker's machine has a considerable advantage, which is, that the column of water which enters into the arms, by pressing from below on the part above, with all the weight of the reservoir, sustains a great part of the weight of the machine, and consequently greatly diminishes the friction of the pivot against the socket in which it turns; while, on the contrary, when the water enters at the top, as in the old reacting machines, which is already very heavy of itself, this flowing water considerably augments the weight, and consequently the resistance.

This disposition cannot be used, except where the bulk of water is not very considerable.

As the arms turn, while the conduit which brings the water is immovable, the pipe that brings the water to enter the collar of the arms is rather less than the collar, so as to leave very little play between them, and is made tight by furnishing this small interval with a leather collar. Another method is by furnishing the tube at bottom, which is fixed, and the moveable collar of the wheel, with several cylindrical and concentric surfaces, which fit one into the other without touching. The water fills the deep and close grooves formed by the cylindrical surfaces, and is sufficient to prevent that which is forced into the wheel from escaping by the sides.

Dr. Robinson describes a superior method of making such a joint, as will admit of a free motion, without any loss or leakage. This is to make the fixed and moveable tubes very true at the joints, so that one enters into the other, but do not touch. The two tubes are to be made exactly of the same diameter within side at the joint, so that a band of thin leather can be applied within side of the joint, to cover the crevice: this must be fixed to the interior of the stationary tube, and the revolving part being smooth within side, will have very little friction, as it is only rubbed by the leather; but there can be no leakage at the joint, because the water will press the leather close to the moving tube, but as much water will get in between the leather and the moving tube as to make it move smoothly.

Theory of Barker's Mill.—This is a most delicate subject,

and upon which it does not appear that sufficient experiments have been made to found a certain theory.

Mr. Waring, of the American Philosophical Society, has given a theory of Barker's mill with the last-mentioned improvement, and, contrary to every other philosopher, he makes the effect of the machine equal only to that of a good undershot wheel, moved with the same quantity of water falling through the same height.

Mr. Gregory, in his *Mechanics*, vol. ii. has given this paper with some corrections, and recommends it as the best theory. The following rules, deduced from his calculus, may be of use to those who may wish to make experiments on the effect of this interesting machine.

1. Make each arm of the horizontal rotatory tube or arm of any convenient length, from the centre of motion to the centre of the apertures, but not less than one-third (one-ninth according to Mr. Gregory) of the perpendicular height of the water's surface above their centres.

2. Multiply the length of the arm in feet by .6136, and take the square root of the product for the proper time of a revolution in seconds, and adapt the other parts of the machinery to this velocity; or if the required time of a revolution be given, multiply the square of this time by 1.629 for the proportional length of the arm in feet.

3. Multiply together the breadth, depth, and velocity *per* second, of the race, and divide the last product by 18.47 times (14.27 according to Mr. Gregory) the square root of the height, for the area of either aperture.

4. Multiply the area of either aperture by the height of the fall of water, and the product by 41½ pounds (55.775 according to Mr. Gregory) for the moving force, estimated at the centres of the apertures in pounds avoirdupois.

5. The power and velocity at the aperture may be easily reduced to any part of the machinery by the simplest mechanical rules.

The only account we have of an actual machine, except the first model by Defaguliers, is by M. Mathon de la Cour, who saw one at Bourg Argental, of the following dimensions. Length of the revolving arms seven feet eight inches, and diameter three inches; diameter of each orifice 1¼ inch; fall of water, from the level surface in the reservoir to the apertures in the revolving arms, twenty-one feet. The water was introduced at the lower end of the revolving axis, through an opening of two inches, the two surfaces being fitted together by grinding.

When this machine was performing no work, and emitted water by one hole only, it made 115 turns *per* minute. This gives a velocity of (24 feet circumference \times 115 =) 2760 feet *per* minute for the hole; but the effluent velocity by theory would be only 2215 feet *per* minute at 21 feet height, and in reality would be little more than six-tenths of that velocity, or about 1370 feet *per* minute. Dr. Robinson supposes even this to be much less than the velocity with which the water issued from the pipe, as we may readily believe, because all the force of the machine was expended in working like a centrifugal pump, to draw the water out of the pipe of supply, with a velocity greater than that with which it would run by the pressure of the column alone. The empty machine weighed 80 pounds, 28½ pounds of which would be borne up by the pressure of the column of 21 feet on a two-inch base, so that the friction of the pivot would be much diminished. We have no account of any work done by the machine, as it was only employed to turn a ventilator for a large hall.

Euler's Machine to act by the Reaction of Water.—His machine consists of a hollow conchoidal ring, that is, a solid shaped just like a large church bell. Suppose also another

bell, of smaller dimensions, placed within the former, and leaving a space all round between the two, the two bells are joined at the lower edges, so that the water cannot escape from the space between them. This machine is mounted on a perpendicular axis, and on the top is a sort of funnel basin, which receives the water from the spout, not in the direction pointing towards the axis, but in the direction of a tangent, and the water is delivered with the precise velocity of the wheel's motion. This prevents any retardation by dragging forward the water. The water passes down from the funnel or basin between the outer conchoid or bell, and the inner conchoid, through spiral channels formed by partitions folded to both conchoids. The curves of these channels are determined by a theory which aims at the annihilation of all unnecessary and improper motions of the water, but which is too abstruse to find a place here. The water thus conducted arrives at the bottom of the space between the two bells. On the lower circumference of this bottom is arranged a number of spouts, one from each spiral channel, which are all directed horizontally, and turned one way in tangents to the circumference.

The same effects will be produced, if we suppose only one bell, with a number of tubes or pipes wound in a spiral direction round its external circumference, the lower ends of each tube being turned horizontally, and in the direction of tangents to the circle which it describes, also the upper or higher extremities of the tubes, connected with a circular superficies into which the water flows from a reservoir. When the machine has this form, it has been shewn by Albert that the effect will increase as the velocity is augmented, and that the maximum effect would be produced if the velocity could be infinite, and that then the effect would be equal to the power. A considerable portion of the power must, however, be consumed, in communicating to the fluid the circular motion of the tubes; and, as the portion thus lost must increase with the velocity of the tubes, the effect will not in reality sustain an augmentation from an increase of velocity, beyond a certain point.

It is plain that this form of the machine must be a most cumbrous mass; even in a small size and height it would require a prodigious vessel, and must carry an unwieldy load. If we examine the theory which recommends this construction, we find that the advantages, though real and sensible, bear but a small proportion to the whole performance of the simple machine, as invented by Dr. Barker. It is therefore to be regretted, that engineers have not attempted to realize the first project.

Machines actuated by the Weight of Water.—The principal of these are breast-wheels, overshot-wheels, chains of buckets, and pressure-engines. All these have an essential difference from the machines which we have yet described, because the water is prevented from descending, unless the machine moves before the water. This is not the case with the machines which receive their motion from the impulse of the water, because the water is suffered to descend and acquire its full velocity before it strikes the machine.

In reasoning without experiment, we might be led to imagine, that, however different these modes of application are, yet whenever the same quantity of water descends through the same perpendicular space, the effective powers of two machines, which are actuated by such fall of water, would be equal, provided that the machines were free from friction, and equally well calculated to receive the full effect of the power of water, and to make the most of it.

For if we suppose the height of a column of water to be thirty inches, and that it rests upon a base or aperture of one inch square, then every cubic inch of water that departs

from the lower end of the column will acquire the same velocity of motion, from the uniform pressure of the thirty cubic inches which are above it, that one cubic inch let fall from the top would acquire in falling down to the level of the aperture, *viz.* such a velocity as in a contrary direction would throw or project it to the level from whence it fell, the weights and velocities in both these cases being equal, the products, or what we have called mechanical powers, will also be equal. We might therefore be led to suppose, that a cubic inch of water, let fall through a space of thirty inches, so as to impinge upon a solid body, would be capable of communicating thereto an equal motion or mechanical effect by collision, as if the same cubic inch had descended through the same space with a slower motion, and produced the effect gradually; for in both cases gravity acts upon an equal quantity of matter through an equal space.

It is true that the gravitating force acts a longer space of time upon the body that descends slowly, than upon the other which falls quickly; but this cannot occasion the difference in the effect: for we find by experiment, that an elastic body falling through any given space will, by collision upon another elastic body which is fixed, rebound nearly to the height from which it fell: or, by communicating its motion to a body equal to itself, will cause that body to ascend to the same height. On these principles we might conclude, as some authors have done, that whatever was the ratio between the power and effect in undershot wheels, the same would hold true in overshot, and indeed in all others.

However conclusive this reasoning may seem, it will appear, in the course of the following deductions, that the effect of the gravity of descending bodies is very different from the effect of the stroke, of such as are *non-elastic*, though generated by an equal mechanical power.

It is true that, in the cases we have above supposed, the power of the fall of water is the same; but the problem proposed to the engineer is, to obtain from it all or as much as possible of the power, and render it applicable to some useful purpose. We have already given our definition of *power*, that it is weight or matter compounded with motion. Now to obtain all the power from any stream of water, we must abstract from it all its weight and all its motion. In undershot wheels, or any others moved by the impulse of the water, we cannot come near this, because we have already shewn, that the greatest effect is produced, when the velocity of the wheel is two-fifths of the velocity of the moving water. The water, after it has finished its effect, is discharged with that velocity; hence it retains and carries away with it three-fifths of its original power. Neither can we obtain the full effect of the weight of the water, for another loss is sustained, in the change of figure which the water experiences, when it strikes the float-board. This is much greater than is usually supposed, in considering machines, although it must be familiar to any one who considers the resistance of a boat, or other body, when drawn through water. No weight is raised in these cases, unless the motion be rapid, (so as to raise a wave before the moving body;) but all the power is expended in changing the figure of the water, by dividing the particles, and putting them in new positions, so that the body can pass between them.

It is to this source that we must look, for the difference between two-fifths of the power, which we find is abstracted from the whole power of the water by an undershot-wheel, and one-third of the power, which is the utmost we can obtain by means of an undershot wheel.

In the other class of machines, which are actuated by the weight of water, we can obtain a much greater share of the power of the descending water. The weight of the water

is borne by the machine, which must therefore receive the whole weight of the water, and the loss is chiefly in the motion which the water still retains after departing from or quitting the machine; but as we are not confined, as in the former instance, to any fixed velocity of motion for the wheel, we may make it move almost as slowly as we please, so that the water will carry away with it a very small share of the velocity which it would have acquired by falling through the height of the fall. Indeed, if we could suppose a wheel to be without friction, and no water to leak or escape from those vessels, or parts of the wheel which contain the water, it would be possible to obtain an effect from it very nearly equal to the power.

Breast-Wheels.—These are very commonly called undershot wheels, because the water runs beneath the wheel, but improperly, because the water does not shoot against the floats of the wheel, or at least the principal power is derived from the weight of the water. A breast-wheel partakes of the nature of both an overshot and an undershot, and is constructed as is represented in *fig. 1. Plate I. of Water-wheels*. The lower part of the wheel is surrounded by a curved wall or sweep of masonry, which is made concentric with the wheel, and the float-boards of the wheel are exactly adapted to the masonry, so as to pass as near as possible thereto without touching it; and the side walls are in like manner adapted to the end of the float-board or sides of the wheel, the intention being, that as little water as possible shall be able to pass by the float-boards without causing the boards to move before it. The water is poured upon the wheel over the top of the breasting at I, the efflux from the mill-dam R being regulated by the sluice or shuttle M, which is placed in the direction of a tangent to the wheel, and is provided with a rack N, and pinion P, by which it can be drawn up so as to make any required degree of opening, and admit more or less water to flow on the wheel.

The water first strikes on the float, and urges it by its impulse; but when the floats descend into the sweep, they form as it were close buckets, each of which will contain a given quantity of water, and the water cannot escape from these buckets except the wheel moves, at least this is the intention, and the wheel is fitted as close as it can be to the race with that view. Each of the portions of water contained in these spaces bears partly upon the wall of the sweep, and partly upon the floats of the wheel; and its pressure upon the floats, if not exceeded by the resistance, will cause the wheel to move; hence the action upon all the floats which are within the sweep of the breasting is by the weight of the water alone; but the water is made to impinge upon the first float-board with some velocity, because the surface of the water in the dam K is raised considerably above the orifice beneath the shuttle where the water issues.

The upper part of the fall at I is rounded off to a segment of a circle called the crown of the fall, and the water runs over it. The lower edge of the shuttle when put down is made to fit to this curve, so as to make a tight joint; and in consequence when the shuttle is drawn up, the water will run between its lower edge and the crown in a sheet or stream which strikes upon the first float that presents itself, nearly in a direction perpendicular to the plane of the float-board, or of a tangent to the wheel. The float-boards of the wheel are directed to the centre, but there are other boards placed obliquely which extend from one float-board to the rim of the wheel, and nearly fill the space between one float-board and the next. These are called rising-boards, and the use of them is to prevent the water flowing over the float-board into the interior of the wheel; but the edges of

these boards are not continued so far as to join to the back of the next float, because that would make all the boards of the wheel close, and prevent the free escape of the air when the water entered into the spaces between the floats.

As the water strikes with some force, the rising-board is very necessary, to prevent the water from dashing over the float-boards into the interior of the wheel.

This is the form of breast-wheel employed by Mr. Smeaton in the great number of mills which he constructed; but although he speaks of the impulse of the water striking the wheel, he always endeavoured to make the top of the breasting or crown of the fall as high as possible, so as to attain the greatest fall and the least of the impulsive action. All rivers and streams of water are subject to variation in height from floods or dry seasons, and in some this is very considerable; it was therefore necessary to make the crown I of the fall at such a height as that in the lowest state of the water R, it would run over the crown in a sheet of three or four inches in thickness, and work the wheel. When the water rose higher in the mill-dam, it would then have a pressure to force it through, and in that case would strike the wheel so as to impel it by the velocity.

Mr. Smeaton was well aware that the power communicated by this impulse was very small. In some cases, where the water was very subject to variation, he used a false or moveable crown, that is, a piece of wood which fitted to the crown I, and raised the surface thereof a foot or more, so as to obtain the greatest fall when the water stood at a mean height; but when the water sunk too low to run over this moveable crown, it could be drawn up to admit the water beneath it. This effect has since been produced in a more perfect manner by making the crown of the fall a moveable shuttle, to rise and fall according to the height of the water in the mill-dam, by which means the inconvenience before-mentioned is avoided.

Improved Breast-wheel, in which the Water runs over the Shuttle.—Fig. 7. is a section of one of this kind. A is the water which is made to flow upon the float-board B, and urges the wheel by its weight only, the water being prevented from escaping or flowing off the float-boards by the breast or sweep D D, and the side-walls which inclose the floats of the wheel. The upper part of the breast D D is made by a cast-iron plate, curved to the proper sweep to line with the stone-work. On the back of the cast-iron plate the moving shuttle *e* is applied; it fits close to the cast-iron so as to prevent the water from leaking between them, and the water runs over its upper edge. F is an iron groove or channel let into the masonry of the side-walls, and in these, the ends of the sliding shuttle are received; *f* is an iron rack, which is applied at the back of the shuttle, and ascends above the water-line where the pinion *g* is applied to it to raise or lower the shuttle. The axis of the pinion is supported in a frame of wood I I; *b* H is a toothed sector and balance-weight, which bears the shuttle upwards, or it might otherwise fall down by its own weight, and put the mill in motion when not intended. G is a strong planking, which is fixed across between the two side-walls, and retains the water when it rises very high, as in time of floods; but in common times the water rises only a few inches above the lower edge of the planking. When the shuttle is drawn up to touch this lower edge, the water cannot escape; but when the shuttle is lowered down, it opens a space *e* through which the water flows upon the float-boards of the wheel. This was the form first adapted for the falling-shuttle, but its construction has since been much improved.

Fig. 4. Plate II. is a section of the most improved form for a breast-wheel, taken from the Royal Armoury Mills, at Vox. XXXVIII.

Enfield Lock, erected by Messrs. Lloyd and Ofel. The general description of this, is like the former, but it is constructed in a better manner, and unites strength with durability. The breast of masonry is surmounted by a cast-iron plate A $2\frac{1}{2}$ feet high, which is let into the masonry of the side walls at each end, and the lower part is formed with a flanch, by which it is bolted to the stone-breast at top. This plate is made straight at the back for the shuttle B to lie against, and it slides up and down. The ends of the gate are guided by iron groove pieces or channels which are let into the stone-work of the side walls, and being made wedge-like, they fix the ends of the cast-iron breast fast in its place. The grooves are not upright, but inclined to the perpendicular so much, that the plane of the gate is at right angles to a radius of the wheel drawn through the point where the water falls upon the wheel. D is a strong plank of wood, extended between the iron grooves just over the shuttle. When the shuttle is drawn up it comes in contact with the lower side of this piece of wood, and stops the water; but the piece D is fixed at such a height, that the water will run clear beneath it, unless its surface rises above its mean height.

The float-boards of the wheel do not point to the centre of the wheel, but are so much inclined thereto that they are exactly horizontal at the point where the water first flows upon them. In this way, the gravity of the water has its full effect upon the wheel, and the boards rise up out of the tail-water in a much better position, than if they pointed to the centre of the wheel; and this is more particularly observable when the wheel is flooded by tail-water penned up in the lower part of the race, so that it cannot run freely away from the wheel. The dimensions of this wheel are as follow:—Diameter 18 feet to the points of the floats, and 14 feet wide; the float-boards are 40 in number, each 16 inches wide, and each rising-board 11 inches wide. The wheel is formed of four cast-iron circles or wheels, each 14 feet 8 inches diameter, placed at equal distances upon the central axis, which is 14 feet 8 inches long between the necks or bearings, and 9 inches square; the bearing-necks are $9\frac{1}{2}$ inches diameter. The wheel is calculated to make four revolutions *per* minute, which gives near $3\frac{1}{2}$ feet *per* second for the velocity with which the float-boards move. The fall of water is six feet, and the power of the wheel, when the shuttle is drawn down one foot perpendicular, equal to 28-horse power.

Breast-Wheel with two Shuttles.—In this wheel the piece of wood marked D in the last figure, is fitted into the groove of the shuttle, and is provided with racks and pinions to slide up and down, independently of the lower shuttle. The intention of this is, to make the lower shuttle rise and fall, according to the height of the water, so that the water shall always run over the top of it, in the proper quantity to work the mill with its required velocity, whilst the upper shuttle is only used to stop the mill by shutting it down upon the lower shuttle, and preventing the water from running over it. This plan is used when the mill is to be regulated by a governor, or machine to govern its velocity; in that case the governor is made to operate upon the lower shuttle, and will raise it up, or lower it down, according as the mill takes too much or too little water, and this regulates the supply; but the upper shuttle is used to stop the mill, and by this means the adjustment of the lower shuttle is not destroyed, but when set to work again, it will move with its required velocity. Fig. 3. Plate II., *Water-wheels*, is a section of one of the water-wheels at the cotton-mills of Messrs. Strutt, at Belper, in Derbyshire. The width of this wheel is very great, and to render the shuttles A B firm, a strong

grating of cast-iron, is fixed on the top of the breast K, and the shuttles are applied at the back of the grating E, so as to slide up and down against it, the strain occasioned by the pressure of the water being borne by the grating. The lower shuttle is moved by means of long screws, *a*, which have bevelled wheels, *b*, at the upper ends, to turn them, by a connection of wheel-work with the wheel-work of the mill. The upper shuttle, A, is drawn up or down by racks and pinions, *c*, which are turned by a winch, or handle. The bars of the grating E are placed one above the other, like shelves, but are not horizontal; they are inclined, so that the upper surfaces of all the bars form tangents to an imaginary circle of one-third the diameter of the wheel described round the centre thereof. These bars are not above half an inch thick, and the spaces between them are $2\frac{1}{2}$ inches. The bars are of a considerable breadth, the object of them being to lead the water, with a proper slope, from the top of the lower shuttle A to flow upon the floats of the wheel. This disposition allows the shuttles to be placed at such a distance from the wheel as to admit very strong upright bars of cast iron to be placed between the wheel and the shuttles, for the shuttles to bear against, and prevent them from bending towards the wheel, as the great weight of water would otherwise occasion them to do. These upright bars are very firmly fixed to the stone-work of the breast at their lower ends, and the upper ends are fastened to a large timber, D, which is supported at its ends in the side walls, and has a truss-framing applied to the back of it, like the framing of a roof, to prevent it from bending towards the wheel. The upright bars are placed at distances of five feet asunder, so as to support the shuttles in two places in the middle of their length, as well as at both ends; and large rollers are applied in the shuttle, where it bears against these bars, to diminish the friction, which would otherwise be very great.

These precautions will not appear unnecessary when the size of the work is known. The wheel is $21\frac{1}{2}$ feet in diameter, and 15 feet broad; the fall of water is 14 feet, when it is at a mean height; the upper shuttle is $2\frac{1}{2}$ feet high, and 15 feet long; the lower shuttle is 5 feet high, and the same length, so that it contains 75 square feet of surface exposed to the pressure of the water: now taking the centre of pressure at two-thirds of the depth, or $3\frac{1}{3}$ feet, we find the pressure equal to that depth of water acting on the whole surface; that is, the weight of $3\frac{1}{3}$ cubic feet of water = 208 lbs. bears on every square foot of surface, which is equal to 15,600 lbs., or near 7 tons on the lower shuttle only; but if we take the two shuttles together, the surface is 112 square feet, and the mean pressure 312 lbs. upon each, or 16 tons in the whole. The wheel has forty float-boards pointing to the centre. The wheel is made of cast-iron. There are two wheels of the dimensions above stated, which are placed in a line with each other, and are only separated by a wall which supports the bearings; for they work together as one wheel, and the separation is only to obviate the difficulty of making one wheel of such great breadth as 30 feet, though this is not impossible, for there is a wheel in the same works 40 feet in breadth, but it is of wood and not in iron, framed in a particular manner, as we shall soon describe.

Mr. Buchanan's Bucket Water-Wheel for a low Fall.—We have already shewn, that where water can be made to act on a wheel by weight, it is much more effectual than when the same water is made to act by impulse; and we shall shew this more fully in speaking of overshot-wheels.

Where the fall is less than half the diameter of the wheel, if the buckets are made in the usual form of the buckets for overshot-wheels, the difficulty of filling them

with water, and the short time they are able to retain the water, are such great defects, that in such cases breast-wheels, with open float-boards, such as we have described, have been found in practice to be more advantageous than bucket-wheels.

Mr. Buchanan suggests, that, by adopting another form of the buckets, they might be so made as to be easily filled, and at the same time capable of retaining the water in a situation to produce nearly its full effect altogether by weight, on a low fall.

In a wheel of this construction, contrary to the usual practice, the water must be poured into the buckets from within the circle of buckets instead of from without the circle of buckets. How the filling of the buckets from within can be accomplished may not at first be obvious; but it may be done without the pentrough, which supplies the water, making any interference with the arms of the wheel, if it is constructed as shewn in *figs. 4. and 5. Plate I. Water-wheels.* *Fig. 4.* is an horizontal section of the wheel, and plan of the pentrough; and *fig. 5.* an elevation of the water-wheel.

The buckets in the figure, empty themselves by means of apertures on the outside of the wheel, which are the whole length of the buckets, but no wider than just sufficient to discharge the water from the buckets when they arrive at the bottom of the wheel, and before they begin to ascend. A A is the pentrough, into which the supply of water is conducted. From B to C a part of the wheel is represented, with the shrouding removed, to shew the form of the buckets, and the situation of the water in them; *a, a, a*, are the apertures by which the water escapes from the buckets; *b* the aperture by which the water enters from the pentrough to the buckets. The plan, *fig. 4.*, shews, that the arms, N N, of the wheel, and the circular rims which support the buckets, occupy only a small part of the breadth of the circular ring of buckets M; so that about one-third of the length of the buckets at each end is exposed on the inside of the circle, and against these parts the penstock is applied, as shewn at A A, and the arms and rim of the wheel, move clear of it; but the buckets, as they pass, receive water, which flows in a continual stream at the orifices, *b, b*, of the pentrough; the buckets there become filled from the inside. The partition-boards or plates which form the buckets are represented by the white lines in *fig. 5.*, and are so shaped, that they will retain nearly the whole of the water until they arrive at the lowest *a*; the water then begins to escape, and by the time that each bucket arrives at the lowest point of the wheel, it will have discharged all the water, and will rise up empty.

This is a truly ingenious contrivance; but we fear that in the execution it would present many difficulties, particularly the ring of buckets M, which could not, we think, be so firmly affixed, supported by the narrow bearing of the two rings and arms N, as to preserve their circular figure for any great length of time; and any bending or warping of such a heavy mass as a water-wheel will soon destroy it. Neither is the advantage which could be derived from receiving the water in close buckets, instead of open float-boards, so great as is generally imagined.

On the Power and Effect of Breast-wheels.—We shall fully examine the different effects of the power of water, when acting by its impulse and by its weight, under the title of *overshot-wheels.* In breast-wheels of the common construction, the effects of impulse and weight are combined; but what is there described being carefully attended to, the application of the same principles in these combined cases will be easy.

All kinds of machines, where the water cannot descend through a given space, unless the wheel moves therewith, are to be considered as of the same nature with overshot-wheels, and equal in power and effect to an overshot-wheel, in which the perpendicular height that the water descends from is the same. All those machines that receive the impulse or shock of the water, whether in an horizontal, perpendicular, or oblique direction, are to be considered of the same nature as undershot-wheels. Therefore, in a wheel which the water strikes at a certain point below the surface of the water in the mill-dam, and after that descends in the arc of a circle, pressing by its gravity upon the floats of the wheel, the power will be equal to the effect of an undershot-wheel, whose fall is equal to the difference of level, between the surface of the reservoir and the point where it strikes the wheel, added to that of an overshot, whose height is equal to the difference of level between the point where it strikes the wheel and the level of the tail-water.

It is here supposed that the wheel receives the shock of the water at right angles to its radii, and that the velocity of its circumference is properly adapted to receive the utmost advantage of both these powers; otherwise a reduction must be made on that account.

Mr. Ostel, an experienced engineer, informs us, that the velocity of the water-wheel's circumference should always be between three and four feet *per* second; but he has not been able to determine which of these two velocities is the best, except in cases where a wheel is subject to be flooded by tail-water; and in that case four feet *per* second is best. Mr. Smeaton advised $3\frac{1}{2}$ feet.

On overshot Water-Wheels.—An overshot-wheel is simply a circular ring of open buckets, so disposed round the circumference of a vertical wheel, as to receive the water from a spout placed over the wheel in such a manner, that the buckets on one side of the wheel shall be always loaded with water, whilst the other side is empty: in consequence, the loaded side will cause it to descend; and by this motion the water runs out of the lower buckets, while the empty buckets of the rising side of the wheel, in their turn come under the spout, and are filled with water.

A machine so simple does not appear to present any difficulties in its execution, which should require any application of theoretic reasoning to remove them; but in reality it is a matter of some delicacy to construct a wheel in such a manner as to obtain the greatest effect from a given fall of water.

It is probable, that the earliest overshot water-wheels consisted of a number of wooden boxes or bowls, fastened on the circumference of the wheel; but these would soon give place to a better mode of construction, in which the circumference of the wheel being surrounded by a circular ring at each side, the space between them was divided into separate buckets by partition-boards. These partitions did not point to the centre of the wheel in the direction of radii, but were inclined thereto nearly in an angle of forty-five degrees. By this means, the water which issued from the spout of the trough above, nearly in an horizontal direction, as a tangent to the wheel, would run into the buckets, and fill them as they arrived in succession at the top or highest point of the wheel; but as the buckets changed their position by the descending-motion of one side of the wheel, they would become inclined, and the water contained in the buckets would begin to run over the edges of the partitions between the buckets, and by the time the bucket arrived at the bottom point of the wheel, the whole of the water would be run out and leave the bucket empty, and they would remain empty whilst they ascended on the opposite side of the wheel. By this

means, a constant preponderance of one side of the wheel would be kept up by the water falling into the buckets at the top of the wheel, and flowing from it at the bottom.

The points chiefly to be considered in constructing an overshot-wheel are, first, that the water shall be applied on the circumference of the wheel, so as to be incapable of descending without communicating motion to the wheel, until the water has descended to its lowest position, and that it shall then quit the wheel entirely; secondly, that the utmost height of fall shall be attained and usefully employed; and thirdly, that the load or resistance to the motion of the wheel shall be so adapted and proportioned to the weight of water which is applied in the descending-buckets of the wheels, that the wheel will move slowly; because we have before shewn, that whatever velocity the wheel moves with, so much velocity the water must retain when it quits the wheel, and will thus carry away some power with it.

We shall now proceed to consider all the particulars which contribute to the attainment of these objects, taking Mr. Smeaton for our guide, and only adding such observations as appear necessary to render his maxims more clear.

I. *On the maximum Effect which can be obtained from a Fall of Water by Means of an overshot-Wheel.*—The effective power of the fall of water must be reckoned upon the whole descent, because it must be raised that height, in order to be in a condition to produce the same effect a second time. The ratio between the powers of the falling water so estimated, and the mechanical effects produced by the wheel at the maximum, deduced from the mean of several of Mr. Smeaton's experiments, is as 3 to 2 nearly. We have before, in our observations upon the effects of undershot-wheels, shewn that the general ratio of the power to the effect, when greatest, was 3 : 1. The effect, therefore, produced by an overshot-wheel, under the same circumstances of quantity and fall of water, is at a medium, double that produced by an undershot. From this, it appears that non-elastic bodies, when acting by their impulse or collision, communicate only a part of their original power; the other part being spent in changing their figure in consequence of the stroke.

The ratio of the power to the effect, computed upon the height of the wheel only, was, at a maximum, as 10 : 8, or as $\frac{5}{4}$, because Mr. Smeaton made the wheel of a less height than the fall of water, in order to allow some run or descent of the water through the spout or trough, which conducted it into the buckets of the wheel. We find the ratio, between the power and effect, to continue the same, in cases where the constructions are similar; hence we must infer, that the effects, as well as the powers, are as the quantities of water and perpendicular heights multiplied together respectively.

II. *On the most proper Height of the Wheel, in Proportion to the whole Descent.*—The preceding observation shews, that the effect which can be obtained from the same quantity of water, descending through the same perpendicular space, is double when it is made to act by its gravity upon an overshot-wheel, to what could be obtained from it when made to act by its impulse upon an undershot-wheel.

Hence it follows, that the higher the wheel is, in proportion to the whole descent, the greater will be the effect; because an overshot-wheel depends less upon the impulse of the water when it first strikes the wheel, and more upon the gravity of the water in the buckets. The water which is conveyed into the buckets can produce very little effect by its impulse, even if its velocity be great; both on account of

the obliquity with which it strikes the buckets, and in consequence of the loss of water occasioned by a considerable quantity of fluid being dashed over their sides. Instead, therefore, of expecting an increase of effect from the impulse of the water occasioned by its fall through some part of the whole height, we should cause it to act through as much as possible of this height by its gravity, by making the diameter of the wheel as great as possible. But a disadvantage attends even this rule; for if the water is conveyed into the buckets with a very small velocity, which must be the case when the diameter of the wheel equals the height of the fall, the velocity of the wheel will be retarded by the impulse of the buckets striking against the water, in order to put it in motion, and much power would be lost by the water dashing over them. In order, therefore, to avoid all inconveniences, the distance of the spout from the receiving-bucket should, in general, be about two or three inches, that the water may be delivered with a velocity a little greater than that of the wheel; or, in other words, the diameter of an overshot-wheel should be two or three inches less than the greatest height of the fall; and yet it is no uncommon thing to see the diameters of these wheels scarcely one-half of that height. In such a construction, the loss of power is prodigious.

It is always desirable that the water should have somewhat greater velocity, than the circumference of the wheel in coming thereon, otherwise the wheel will not only be retarded by the buckets striking the water, but thereby dashing a part of it over so much of the power is lost.

The velocity that the circumference of the wheel ought to have, will be known by what we shall say next, and the depth of column requisite to give the water its proper velocity, is easily computed from the rules and tables given in this article, and will be found much less than what is generally supposed.

This maxim obliges us to use a wheel, whose diameter is nearly equal to the whole fall; but we shall not gain any thing by employing a larger wheel. It is true, we could then apply the water upon a part of the circumference where the weight will act more perpendicularly to the radius, but we should lose more, by the necessity of discharging the water at a greater height from the bottom, because the water, in all cases, begins to run out of the buckets long before they arrive at the bottom of the wheel.

Suppose the buckets of both wheels equally well constructed in either case, whether the wheel is only as high as the fall, or of a greater height, then the heights above the bottom, where they will discharge the water, will increase in the proportion of the diameter of the wheel. That we shall lose more by this, than we gain by a more direct application of the weight, is plain without any further reasoning, by taking the extreme case, and supposing our wheel enlarged to such a size, that the useless part below would be equal to our whole fall. In this case, the water would be spilled from the buckets as soon as it is delivered into them. All intermediate cases, therefore, partake of the imperfection of this. It was the object of Mr. Buchanan's bucket-wheel, which we have already described, to avoid this difficulty, and employ a height of fall which bore only a small proportion to the whole height of the wheel. This observation necessarily leads us to consider the best form for the buckets.

III. On the best Form for the Buckets of overshot Wheels.—It is impossible to construct the buckets so that they will remain completely filled with water till they reach the bottom of the wheel: indeed, if the buckets were formed by partitions directed to the axis of the wheel, the whole water

must run out by the time they have descended to the level of the axis; and, in consequence, there must be a great diminution in the mechanical effect of the wheel. Millwrights have, therefore, turned their chief attention to the determination of a form for the buckets which shall enable them to retain the water through a great portion of the circumference of the wheel. An inspection of *figs. 2 and 3* will shew at once the proper form which has been established by long practice. These are called elbow-buckets, because each partition is formed by two boards, which are put together with an angle or elbow. The rule for setting these out is, to divide the wheel into the number of buckets it is intended to have; then take four-fifths of the space or interval between two partitions for the depth of the shrouding, that is, the breadth of the circular rings at the sides of the wheel, which form the ends of the buckets, and are called the shrouds; whilst the planking, which forms the bottom of all the buckets, is called the sole of the wheel. That board of each partition which is in the direction of a radius to the wheel, rises from the sole half the depth of the shroud; the other board of the bucket is so inclined, that its outer end shall be advanced beyond the line of the next radius-board, if it was produced.

It is a great advantage to make the partitions of the buckets thin, particularly the edges of the partitions, which will meet and divide the stream of water flowing upon the wheel; and if these edges are not made sharp, they will splash the water about; the edges are, therefore, finished by iron-plate, or it is better to make all the inclined parts of the partition of iron-plate. The greater number of buckets, and the shallower they are, the more regularly the wheel will act. The limits are, that the mouths of the buckets shall be of such width as to allow the air to escape, at the same time that the stream of water flows in; and also that the breadth of the wheel shall not be extravagantly great, to make its buckets contain as much water as would produce the power required from the wheel.

The loss of water, at the lower part of the wheel, will very much depend upon the proportion of water which is poured into each bucket. It is evident, that if the buckets, of whatever form they are made, were totally filled when at the top of the wheel, they must begin to spill the water immediately when they departed from that position. But, on the other hand, if only a part of the content of each bucket is filled with water, then it will bear a greater degree of inclination, and be a longer time before the water will begin to spill from the bucket. This is a reason for making large buckets, and filling only a part of their contents. In practice a medium must be struck between these contending circumstances, and the wheel will act to advantage.

It has been proposed to apply another bend to the partition-boards of each bucket which shall be beyond the inclined board that we have described, and shall be concentric with the rim of the wheel, in the same manner as is represented in Mr. Buchanan's wheel, *fig. 5*. It is true that this form would retain the water from spilling for a longer time, and thus be an advantage; but it is not favourable for admitting the water into the buckets when at the top of the wheel.

The inclined boards, when made as we have described, may be exactly in the line of the stream of water, which issues from the spout when it passes beneath such stream; and in this way, if the edge of the inclined board is made thin, there will be as little splashing of the water as possible. But by the addition of another part to the edge of the partition, which is concentric to the circle of the wheel, the stream of water cannot be made to proceed exactly in the

line of the partition, and will therefore splash the water. The splashing may appear immaterial, but it is in reality very prejudicial, because the broken water fills the mouth of the bucket, and prevents the air from getting out readily, and it is for this reason that it is very necessary to allow so much of the fall above the height of the wheel, as will make the water run into the buckets, with a little greater velocity than the motion of the wheel.

Dr. Robinson, in the *Encyclopædia Britannica*, described a plan for the buckets of an overshot wheel, which was invented by Mr. Robert Burns, millwright, and executed by him at a cotton-mill in Scotland: it is shewn in *fig. 5. Plate II. Water-wheels*. In this way, the wheel has two ranks of buckets, one within the other. The buckets consist of a partition A B, in the direction of a radius of the wheel, which is joined to another B C, inclined to that, and also to a third C D, which is concentric with the rim of the wheel.

The bucket is divided into two, by a partition L M, also concentric with the rim of the wheel, and so placed as to make the inner and outer portions of the bucket nearly of equal capacity. It is evident, without any farther reasoning, that this partition will enable the double bucket to retain its water much longer than the single one could. When they are filled only one-third, they retain the whole water at eighteen degrees from the bottom of the wheel, and they retain half of the water at eleven degrees. The only objection is, that they do not admit the water quite so freely as buckets of the common construction.

This arises from the air, which must find its way out to admit the water, but is obstructed by the entering water, and occasions a great spluttering at the entry. This may be entirely prevented, by making the spout considerably narrower than the wheel, and will leave room at the two ends of the buckets for the escape of the air. It was found in practice, that a slow moving wheel, allowed one half of the water to get into the inner buckets, especially when the partitions which form the inner buckets, did not altogether reach the radius drawn through the lip D of the outer bucket. The doctor considers this as a very great improvement of the bucket-wheel; and when the wheel is made of a liberal breadth, so that the water may be very shallow in the buckets, it seems to carry the performance as far as it can go. Mr. Burns made the first trial on a wheel of twenty-four feet diameter, and its performance is manifestly superior to that of the wheel which it replaced, and which was a very good one. It has also another valuable property. When the supply of water is very scanty, a proper adjustment of the stream of water issuing from the spout, will direct almost the whole of the water into the outer buckets; which, by placing it at a greater distance from the axis, makes some addition to its mechanical energy.

IV. *Concerning the proper Velocity of the Circumference of an overshot Wheel, in order to produce the greatest Effect.*—If a body of water is let fall freely from the surface of the water in the upper reservoir to the bottom of the descent, it will take a certain time in falling; and in this case, the whole action of gravity will be spent in giving the water a certain velocity. But if this water in falling is intended to act upon some machine, so as to produce a mechanical effect, the falling water must be retarded, because a part of the action of gravity is then spent in producing the effect, and the remainder only will give motion to the falling water, which motion it will retain, after it has quitted the machine. On this principle, the slower a body descends the greater portion of the action of its gravity can be applied to pro-

duce mechanical effect, and in consequence the greater that effect will be.

If a quantity of water falls from a stream, into each bucket of an overshot-wheel, it is there retained until the wheel, by moving round, discharges it. Now, the slower the wheel moves, the more water each bucket will receive, because it remains a longer time beneath the spout, so that what is lost in the speed with which the wheel moves, is gained by the pressure of a greater quantity of water acting in the buckets at once; and if considered only in this light, the mechanical power of an overshot-wheel to produce effects will be equal, whether it moves quick or slow. The popular reasoning adduced to prove this has been of the following kind. Suppose that a wheel has thirty buckets, and that four cubic feet of water are delivered in a second on the top of the wheel, and discharged, without any loss by the way, at a certain height from the bottom of the wheel.

It is clear that this stream will supply the same quantity, whatever is the rate of the wheel's motion; and the buckets must be of a sufficient capacity to hold all the water which falls into them when the wheel moves very slow. Suppose this wheel employed to raise a weight of any kind, for instance to draw a basket of coals out of a deep pit or mine, and that the rope winds upon a barrel of such size that the basket will be drawn up with the same velocity as the water in the buckets descends. Suppose, further, that the wheel will make four revolutions in a minute, or one turn in fifteen seconds, when the load or weight in the basket which forms the resistance to the motion of the machine is one-third of the load of water contained in the buckets of the wheel.

Now, during the time of one revolution, sixty cubic feet of water will have flowed into the thirty buckets, and each have received two cubic feet. In this case, the basket may contain a weight equal to twenty cubic feet of water, which weight will be drawn up a height equal to one circumference of the wheel, during one turn of the wheel, or in fifteen seconds of time.

Now suppose the machine so loaded, by making the basket more capacious, that the wheel can only make two turns in a minute, or one turn in thirty seconds, then each descending bucket of the wheel will receive four cubic feet of water. If the basket contained a double weight, *viz.* equal to forty cubic feet, the effect produced by the machine would be the same as before, because the velocity is only one half; but we find in practice, that it will raise more than in this proportion when it moves slower, for if we attend to what we have just observed of the falling body, we find that so much of the action of gravity as is employed in giving motion and velocity to the wheel and water therein, must be subtracted from its pressure upon the buckets. The product made by multiplying the number of cubic inches of water which act on the wheel at once by its velocity, will be the same in all cases; yet, as each cubic inch, when the velocity is greater, presses more lightly upon the buckets than when the velocity is less, the power of the water to produce effects will be greater in the less velocity than in the greater. This leads us to the general rule, that the less the velocity of the wheel, the greater will be the effect produced by any given quantity, and fall of water.

A confirmation of this doctrine, together with the limits it is subject to in practice, is a matter of experiment and observation which has been ably decided by Mr. Smeaton. The velocity of the wheel should not be diminished, further than what will produce some solid advantage in point of power; because, as the motion is slower, the buckets must be made larger, that the increase of their weight may com-

penfate for the fownefs of their motion. The wheel being thus more loaded with water, the ftreffs upon every part of the work will be increafed in proportion.

The beft rule for practice will be, to make the velocity of the circumference a little more than three feet in a fecond.

Experience confirms, that this velocity of three feet in a fecond, is applicable to the greateft overfhot wheels as well as the fmalleft; and all other parts of the work being properly adapted to this velocity, the fall of a given quantity of water, will produce very nearly the greateft effect poffible. But it is alfo certain from experience, that large wheels may deviate further from this rule before they will lofe their power, by a given aliquot part of the whole, than fmall ones can be admitted to do; for inftance, a wheel of twenty-four feet high may move at the rate of fix feet *per* fecond, without lofing any confiderable part of its power. This may perhaps be accounted for, when we confider how fmall a proportion of the whole fall is requifite to give the water the proper velocity which the wheel ought to have; whilft in a fmall wheel, the fame height muft be allowed for that purpofe, and confequently, a greater proportion of the whole height. On the other hand, Mr. Smeaton tells us, that he had feen a wheel of thirty-three feet diameter that moved very ftadily and well, with a velocity but little exceeding two feet *per* fecond.

There is a natural wifh to fee a machine move briskly; it has the appearance of activity: but a very flow motion always looks as if the machine was overloaded. For this reafon, mill-wrights have always yielded flowly, and with reluctance, to the advice of Mr. Smeaton, but they have yielded; and we now fee them adopting maxims of conftruction more agreeable to found theory, that is, making their wheels of great breadth, and loading them with a great deal of work. The reluctance to adopt this fyftem did not arife folely from prejudice, but from a real inconvenience attending the flow motion of the wheel when the refiftance which is oppofed to its motion, and which is the caufe that it moves flowly, is not uniform in the different parts of a revolution.

In all machines, there are fmall inequalities of action which are unavoidable; and in fome machines very great inequalities arife, from the intermitting motions of cranks, ftampers, and other parts which move unequally or reciprocally. When a water-wheel is employed to give motion to fuch machines, it may be fo refifted or loaded, as to be nearly in equilibrio with its work, in the moft favourable pofition of the parts of the machine; but when thefe change into a lefs favourable pofition, the machine may flop the wheel altogether, or at all events hobble, and work very irregularly. And for the fame reafon that a water-wheel accommodates its motion very quickly to the refiftance it is to overcome, fo all tendency to irregular motion is increafed. A wheel, when its load is increafed, moves more flowly, and receives more water into each bucket; thereby taking to itfelf a weight of water equal to overcome its load, and on the other hand by moving quicker, it takes lefs water into each bucket when the load is diminifhed. But thefe changes do not take place infтанtaneously, becaufe it can be only in the moment that each bucket paffes beneath the ftream, that the fhare of water it fhall have, will be influenced by the rate of the wheel's motion. When a bucket is once filled it continues with that charge until it arrives at the bottom of the wheel.

This felf-regulating property of the wheel can only apply in cafes of fmall and permanent changes of refiftance,

for it always comes too late to correct fudden and confiderable changes in the refiftance; then it acts in the contrary direktion. Suppofe, for inftance, an overfhot wheel is employed to work a fingle pump by means of a crank, the refiftance of this machine will be continually varying; it will be nothing during one-half of the period of the revolution when the pump is not drawing any water, and during the other half it will be in a conftant ftate of increafe and diminution. Now, during the time this wheel has nothing to do, it will turn round very quickly, and therefore each bucket will receive very little water; confequently, when the wheel comes to be refifted, the wheel will have fo little water in its buckets, that it will perhaps be quite ftopped: in this cafe, the bucket beneath the fpout will receive water until it is quite full, and then the water will run over and fill fo many of the buckets beneath it, as to put the wheel in motion flowly; in confequence, the fucceeding buckets will receive a large fhare of water during the half revolution when the pump makes its ftroke; but when this is finifhed, and the refiftance ceafes, the wheel being well loaded with water, will in confequence move very rapidly for a half revolution, and its buckets will receive very little water.

This is indeed an extreme cafe of irregular refiftance, and muft be remedied by applying two pumps inftead of one, or a balance-weight, or a fly-wheel; but the fame principle will apply in cafe of fmall irregularities. In all cafes, the refiftance muft be reduced to a great degree of uniformity, before a water-wheel can be applied to it with advantage, particularly if the wheel is intended to move flowly, with a view of obtaining the greateft power, the irregularities will then have more ferious confequences.

A little more velocity enables the machine to overcome thofe increafed refiftances by its *inertia*, or the great quantity of motion inherent in it. Great machines poffefs this advantage in a fuperior degree, and will confequently work ftadily with a fmall velocity. In all cafes, the machine muft have fo much moving matter in it as is fufficient to overcome the irregularities, and regulate the motion of the wheel. If this is not already found in the machine, as in the mill-ftones of a corn-mill for inftance, the weight muft be placed in the water-wheel itfelf, or in a fly-wheel applied for the purpofe.

Mr. Buchanan meafured the quantity of water which a cotton-mill required, when going at its common velocity; and when going at half that velocity. The refult was, that the laft required juft half the quantity of water which the firft did. In the experiments, the quantities of water were calculated from the depth of water and apertures of the fluires.

From which experiments, he inferred that the quantity of water neceffary to be employed in giving different degrees of velocity to a cotton-mill, muft be nearly as the velocity. The water from the cotton-mill on which he made the obfervation, falls a little below it, into a perpendicular-fid pond, which ferves as a dam for a corn-mill. By meafuring the time which the water took to rife at a certain height in that pond, he determined the expendifure of water when the corn-mill moved at its common velocity; and alfo when it moved at nearly half that velocity.

The refult of thefe experiments approached very nearly to the former, and all the differences could be accounted for, by a fmall degree of leakage, which took place at the fluires on the lower end of the pond; and the time being greater when the mill moved flowly, the leakage would of courfe be greater.

In these experiments, the motion of the water-wheel being exactly proportioned to the quantity of water expended, the load upon the wheel must have been equal when it moved quick or slow, that is to say, the buckets must have been equally filled when the wheel moved at its ordinary motion, or at half that motion.

The effect, therefore, of letting more water on a wheel when the resistance continues the same, is not to lodge a greater quantity in each of the buckets, but to supply the same quantity to each bucket when the wheel is in a greater motion.

The greatest velocity that the circumference of an overshot wheel can acquire, depends jointly upon the diameter or height of the wheel, and the velocity of falling bodies; for it is plain, that the velocity of the circumference can never be greater, than to describe a semicircumference, in the time that a body let fall from the top of the wheel would descend through its diameter, nor indeed quite so great; as a body descending through the same perpendicular space cannot perform its course in so small a time, when passing through a semicircle, as would be done in a perpendicular line. Thus, if a wheel is sixteen feet one inch diameter, a body will fall through the line of its diameter in one second: this wheel, therefore, can never arrive at a velocity equal to the making one turn in two seconds. An overshot wheel can never come near this velocity, for when it acquires a certain speed the greatest part of the water is prevented from entering the buckets; and the rest, at a certain point of its descent, is thrown out again by the centrifugal force. The velocity, when this action will begin to take place, depends in a great degree upon the form of the buckets as well as other circumstances; so that the utmost velocity that an overshot wheel may be capable of is not to be determined generally; and indeed the knowledge of it is not at all necessary in practice, because a wheel, in such case, would be incapable of producing any mechanical effect.

V. *On the proper Load for an overshot Wheel, in order that it may produce a maximum Effect.*—The maximum load or resistance for an overshot wheel, is that which will reduce the circumference of the wheel to its proper velocity, of three or three and a half feet *per* second; and this will be known, by dividing the effect it ought to produce in a given time, by the space intended to be described by the circumference of the wheel in the same time; the quotient will be the resistance to be overcome at the circumference of the wheel, and is equal to the load required, the friction and resistance of the machinery included.

VI. *On the greatest Load that an overshot Wheel can overcome.*—The greatest load an overshot wheel can overcome depends upon the magnitude of the buckets; and the resistance which will stop the wheel, must be equal to the effort of all the buckets in one semicircumference, when quite filled with water.

The structure of the buckets being given, the quantity of this effort may be assigned, but is not of much importance in practice, as in this case also, the wheel loses its power; for though the water makes the utmost exertion of gravity upon the wheel, yet, being prevented by a counterbalance from moving at all, it is not capable of producing any mechanical effect, according to our definition. An overshot wheel, generally ceases to be useful before it is loaded to that pitch, for when it meets with such a resistance as to diminish its velocity to a certain degree, its motion becomes irregular; yet this never happens until the velocity of the circumference is reduced to less than two feet *per* second, where the resistance is equable, as appears not

only from the preceding specimen, but from experiments on larger wheels.

VII. *Construction of the Pentrough for supplying the Water to overshot Wheels.*—We have hitherto spoken of the stream of water, as if it issued from a spout nearly in an horizontal direction, or with only so much inclination as will make the line of the stream correspond with the direction of the oblique part of the bucket-board. This is the ancient, and still the common way; Mr. Smeaton's, which is a much better, is shewn in *fig. 2. Plate I. Water-wheels.* G represents the pentrough through which the water flows, and FF strong cross-beams on which it is supported; the wheel is situated very close beneath the bottom of the trough, as the figure shews. EE are two arms of the wheel, which are put together, as shewn in *fig. 7. DB* is the wooden rim of the wheel; the narrow circle beyond this is the section of the sole planking, and on the outside of this the bucket-boards are fixed as the figure shews; one of the bottom boards, *b*, of the trough at the end is inclined, and an opening is left between that end and the other boards of the bottom, to let the water pass through; this opening is closed by a sliding shuttle, *c*, which is fitted to the bottom of the trough, and can be moved backwards and forwards by a rod, *d*, and lever, *e*, which is fixed into a strong axis *f*; this axis has a long lever on the end, which, being moved by the miller, draws the shuttle along the bottom of the trough, and increases or diminishes the aperture through which the water issues. The extreme edge of the shuttle is cut inclined, to make it correspond with the inclined part *b*, and by this means it opens a parallel passage for the water to run through, and this causes the water to be delivered in a regular and even sheet; and to contribute to this the edges of the aperture where the water quits it, are rendered sharp by iron plates; the shuttle is made tight where it lies upon the bottom of the trough by leather, so as to avoid any leakage when the shuttle is closed. When the wheel is of considerable breadth, the weight of the water might bend down the middle of the trough until it touched the wheel; to prevent this, a strong beam, *O*, is placed across the trough, and the trough is suspended from this by iron bolts which pass through grooves in the shuttle, so that they do not interfere with the motion of the shuttle.

Fig. 3. of the same plate is an overshot wheel, for which Mr. Nouaille took a patent in 1813; he recommends that the water-wheel be made the full height of the fall of water, and that the water be applied upon the wheel at 53 degrees from the vertex. The pentrough is made nearly on the same plan as Mr. Smeaton's. OR is the trough, *bg* the end inclined in the direction in which the water is intended to be directed, *f* the shuttle, sliding horizontally on the bottom of the trough, *cde* the lever for drawing the shuttle, to which motion is given by a regulating screw *a* and nut *b*.

Fig. 9. Plate II. Water-wheels, is the method of laying on water, which has for several years been in common use in Yorkshire and the north of England. In this the water is not applied quite at the top of the wheel, but nearly in the same position as the last described; but the advantages of this wheel over all others is, that the water can be delivered at a greater or less height, according to the height at which the water stands in the trough; but in all the preceding methods if the water is subject to variations of height, as all rivers are, then the wheel must be diminished, so that in the lowest state of the water it will stand a sufficient depth above the orifice in the bottom of the trough to issue with a velocity rather greater than the motion of the wheel. In this case, when the water rises to its usual height, or above it, the increase of fall thus obtained is very little advantage to the wheel; the improved

wheel can at all times take the utmost fall of the water, even when its height varies from three to four feet. *AA* is the pentrough made of cast-iron; the end of it is formed by a grating of broad flat iron bars, which are inclined in the proper position to direct the water through them into the buckets of the wheel. The spaces between the bars are shut up by a large sheet of leather, which is made fast to the bottom of the iron trough at *a*, and is applied against the bars; and the pressure of the water keeps it in close contact with the bars, so as to prevent any leakage. This is the real shuttle, and to open it so as to give the required stream of water to the wheel, the upper edge of the leather is wrapped round a smaller roller *b*; the pivots at the ends of this roller are received in the lower ends of two racks, which are made to slide up and down by the action of two pinions fixed upon a common axis which extends across the trough; this axis being turned, raises up or lowers down the roller, and the leather shuttle winds upon it as it descends, or unwinds from it as it ascends, so as to open more of the spaces between the bars, or close them as it is required. In order to make the roller take up the leather, and always draw it tight, a strap of leather is wound round the extreme ends of the rollers, beyond the part where the leather shuttle rolls upon it. These straps are carried above water and applied on wheels, which wind them up with a very considerable tension by the action of a band and weight wrapped on the circumference of a wheel, which is on the end of the axis of those wheels.

The water runs over the upper side of the roller, and flows through the spaces between the grating into the buckets of the wheel; the descent of the water passing through the bars, and afterwards in falling before it strikes the bottom of the bucket, is found fully sufficient to produce the necessary velocity of the water, for a fall of four inches produces a velocity of more than four feet *per second*.

We recommend this as the best method of applying the water, as we see in all other forms that a much greater portion of the fall is given up in order to make the water flow into the wheel; not that any such depth as is commonly given is at all necessary, but the aperture in the trough must be placed so low that the water will run through it in the very lowest states of the water, otherwise the wheel must stop at such times.

On the Manner of framing Water-wheels.—The weight of every wheel must be supported by its axis, which therefore demands the first consideration. If the axis is to be of wood it should be made of a tree of hard and durable wood, of a length and size proportioned to the size and weight of the wheel; into each end a gudgeon or centre should be fixed for the wheel to turn upon. There are two methods of fixing the gudgeon into a wooden axis; one is, by forming the gudgeon with a cross, which is let into the end of the tree, and fastened by screws, and the wood is compressed round the cross by two or three iron hoops, fitted on the end of the tree and wedged; this is explained in the article *MILL-Work*. The other method is, to make a strong iron box in a piece with the gudgeon, into which box the end of the tree is received and secured by wedges. The box being of an octagon shape, and the wood being cut to the same figure, it cannot slip round within the box.

Of late years it has been usual to make the great axis of water-wheels of cast-iron, which is a very good plan, provided the axis is made of sufficient dimensions. This was first practised by Mr. Smeaton, but he was rather unfortunate, as several of them broke after having been many years in use: he then employed hollow tubes of cast-iron of large dimensions and considerable thickness of metal. Even

now that the strength of cast-iron is better understood, it is not uncommon for the axis of a water-wheel to break, particularly in cold and frosty weather, and for this reason some millwrights use wrought iron, but the hollow tube is so much stronger, as to be very secure from accident.

In an iron axis it is advisable to make the bearings of the axis close to the sides of the water-wheel, and leave the ends of the axis projecting beyond the bearings, in order to attach the cog-wheel, by which the power of the wheel is to be communicated to other machinery. This diminishes the length of the axis between the bearings, and renders it much stronger; wooden axes must have the gudgeons at the extreme ends.

The next point to be considered is, the best means of affixing the arms of the wheel firmly to the axis. If the arms are of wood, and the axis also, the most obvious plan is to mortise the arms into the axis; but this is the worst method that can be adopted, because the axis is much weakened, and the water being admitted into the centre of the tree causes it soon to decay, nor can an arm be easily replaced without taking all the wheel to pieces.

A better way is to use eight timbers for the arms, and put them together so as to intersect each other at right angles, (as is shewn in *fig. 7. Plate I.*) leaving a square opening in the centre for the reception of the axis, which is made up to a square by adding pieces of wood to it, and the wheel is fastened on by wedges. The only objection to this is, that the arms are weakened by intersecting each other, and they support the circular rim of the wheel in unequal segments.

In Mr. Buchanan's water-wheel, which we have before described in *figs. 4 and 5, Plate I. Water-wheels*, is a particular construction of the arms formed by thin planks of wood. He states that this plan is applicable to any kind of water-wheel; and since 1790, when he first constructed a wheel with arms on that principle, a considerable number of large wheels have been erected in Scotland on the same plan. It is evident that arms, such as are commonly fixed in mortises in the axis, are weakest in one direction, and that commonly in the direction of the strain. To remedy this defect the feather-pieces *FF* are applied all round, having their broadest ends towards the centre of the wheel, and being at right angles to the breadth of the principal arms. In order to unite them strongly to the principal arms, and connect the whole more firmly together, a ring of iron, *R*, is applied on each side; blocks of wood being put in the vacant spaces between, and the keys or wedges, *KK*, bind the whole close to the axis.

The very best method of uniting the arms to the axis is to have a cast-iron centre-piece, or strong hoop, to fit on the wooden axis with a broad projecting flanch round it, against the flat surface of which the arms of the wheel are applied, and the intervals between them filled up by wooden blocks or wedges; the arms and blocks are firmly bound to the iron flanch by iron rings applied to the arms on the opposite side to the flanch, with screw bolts to go through the whole. This same plan is applicable to an iron axis, and will be more clearly understood by a reference to the article *MILL*, and *Plate XXXIV. Mechanics*; but it is there described that the broad circular flanch to screw the arms against, is cast in the same piece with the axis. This was Mr. Smeaton's original plan, but the flanch should be made in a separate piece, and fastened on the axis with wedges; for if cast in the same piece, the contraction of the metal contained in the flanch when cooling, renders the metal of the axis spongy at the part where it joins to the flanch, and causes them to break at that part. Sometimes the cast-iron centre-piece is made with a

distinct cell to receive each arm, and they are fastened into the cells by wedges and screw-bolts, but a flat flanch with the intervals filled up by blocks is more simple and secure. Modern wheels are very frequently made with cast-iron arms, which in this case are attached to the axis by a similar centre-piece.

The circular rims of water-wheels are commonly made of wood, put together in two or three thicknesses, the joinings of one ring not coinciding with those of the other, and 8 or 10 segments in each thickness, according to the size of the wheel; the thicknesses are united together by rivets. The arms are attached to the ring by notching them in, and securing them by bolts. Cast-iron rings are now generally used, and with great advantage, because the necessary mortises can be made in iron, without weakening the ring; but the strength of a wooden ring is greatly impaired by the mortises through it.

The number of rings in a wheel depend upon its breadth; when the wheel is four feet wide, two rings will support the float-boards or buckets, but the rings should not be more than five feet asunder, or the floats may bend and yield; for want of a sufficient support each ring is framed with its set of arms, so that every one derives its strength from the axis. When a wheel is of great breadth, the whole will be very much strengthened, by applying oblique braces, extending from the centre-pieces of the outside rings to the circumference of the middle ring, by firmly attaching these oblique braces to the arms of all the rings which they intercept; they form truss-frames which prevent the wheel and the axis from bending by its weight: this is particularly useful in wide overshot wheels.

In breast and undershot wheels the float-boards are nailed to pieces of wood called starts, which are fixed into the mortises in the rings, and project outwards for that purpose.

In overshot-wheels, the rings of the wheels are covered by boards laid parallel to the axis, well jointed together, and spiked down to the rings like the boards of a floor to the joists. This boarding forms a close cylinder, which is called the sole of the wheel, and is the foundation for the buckets. When the rings of the wheel are of iron, holes are left in the caltings in the edge of the rings, at regular distances round the circumference, and these are filled up with plugs of wood, into which the nails can be driven to fasten on the boarding of the sole. The sole of the wheel is sometimes made of iron plates rivetted together, and rivetted also to the rings of the wheel.

At the ends of the sole-boards, two circular rings of wood or iron, called shrouds, are fitted on perpendicularly to the sole to form the ends of the buckets; and it is usual, if the wheel is wide, to apply a shrouding over each ring of the wheel, and then the buckets are divided into lengths of about four or five feet. In the flat surfaces of the shroudings, grooves are made for the reception of the ends of the bucket-boards. It is usual to make the first board, which is in the direction of a radius, of wood, and the outside one is generally made of iron plate; but sometimes the whole are made of plate iron, and both parts of the buckets are then bent up out of one piece, and the ends of the plate; and also that part of the edge which is to apply to the sole, is turned square to lie flat against the sole and the shrouding, so that rivets and nails may unite all together, and make water-tight joints.

When the shrouding is of cast-iron, it is made to serve instead of the rings of the wheel, because it has sufficient strength to serve both purposes: the arms of the wheel are in this case applied flat against the ring of shrouding, and bolted to it.

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The breast-wheel, *fig. 3. Plate II. Water-wheels*, at Messrs Strutt's works, which we have already noticed, is deserving of further notice from the manner of putting it together. The rings of the wheel are made of cast-iron, and the float-boards are included between the rings in the manner of an overshot wheel, but the arms are only of wrought iron, being made of small round iron rods, which are very light, and have little strength to resist bending; but as they are all tied in from the centre, the ring cannot deviate from its true circular figure, and to sustain the wheel sideways, oblique bars are extended from the centre-pieces at each end of the axis, and are united to the circular ring in the middle of its breadth, which is 15 feet. We have seen two overshot-wheels of 24 feet diameter, and 9 feet broad, made in the same way. It is plain that in this construction the axis of the wheel can do no office but to support the weight of the wheel; for though these arms are sufficiently strong for that purpose, they can have little strength by way of levers to transmit the force of the circular motion of the rim of the wheel to the axis; but the power is transmitted in a better way than from the axis, *viz.* by a ring of cogs screwed to the circular rim of the wheel, and working in a pinion which conveys the motion to the mill. There is another similar ring of cogs at the other side of the wheel, which works into a pinion fixed on the same shaft, by this means nearly all the strain is taken from the axis of the water-wheel; for the pinion is placed on the descending side of the wheel, so that the weight of the water acting on the float-boards is immediately transmitted to the pinions by the strength of the rings of the wheel.

This method of transmitting the power is also applied to other wheels than those which are made with slight arms like the above; the ring of cogs is sometimes placed in the middle of the breadth of the wheel, and then acts upon one pinion, but it is much better to place it at one side or both sides, if the wheel is very broad, because the circle of the teeth may then be made rather less than the diameter of the rings of the wheel, and the side of the ring being closely fitted to the stone-work of the race, the water may be excluded from the cogs.

It is obvious that of the various constructions of water-wheels, that is the strongest which communicates its motion by means of a ring of cogs immediately attached to its rim, where the power of the water is also applied, the least possible strain being thus thrown on its arms and axis.

The only objection to this plan is, that as the teeth of the cog-wheel are in most cases constantly wet, which prevents the grease from adhering, the usual mode of occasionally greasing the cogs is of little or no use, and the dirt in the water grinds away the teeth; or, were the water even free from dirt, there would be much unnecessary friction and waste of power.

Greasing Machine for the Cog-Wheel of a Water-Wheel.—Mr. Buchanan mentions two water-wheels of this kind, in which the rings of the teeth were wearing very fast, and knowing the trouble and expence of renewing them, he was solicitous to discover some means of rendering them more durable. The only way which presented itself was by some contrivance to keep them well greased.

This he did by a machine shewn in *fig. 8. Plate 1. Water-wheels*; it is nothing more than a kind of pinion, with one or more of its teeth made hollow to contain the greasy substance, and the metal plate of which the hollow cog is composed is perforated with small holes, for exuding the grease through those parts which come in contact with the teeth of the wheel.

Fig. 8. is a section of the greasing machine; A B represents part of the ring of teeth on the circumference of the

N

water-wheel. The greasing-pinon which works in these teeth is mounted on an axis, as is clearly shewn.

N O a retarding lever, of which N is the fulcrum, and O a weight to make it press on the axis of the greasing-pinon, so as to cause a resistance, and make the cogs of the wheel press forcibly on the cogs of the pinion.

G H I K, the hollow teeth for containing the grease; they are made of copper-plate or iron; and to make the perforated sides of the greasing leaves come in close contact with the face of the teeth of the wheel, the lever N O, with a small weight on it, acts on a pulley fixed on the axle of the pinion, and serves to retain it.

E F, &c. the solid teeth of the pinion, made of wood; there are sliders which open for admitting the grease into the hollow teeth at their ends.

The number of leaves in the greaser should be such, that those containing the grease shall apply themselves in the course of several revolutions of the wheel to each of its teeth. Mr. Buchanan found a greaser of 12 leaves, 4 of which contained grease, had this effect upon a wheel of 304 teeth; and one of 13 leaves, with one tooth only filled with grease, served a wheel of 168 teeth.

It is best to use a mixture of tallow, oil, and black lead for greasing, made of a consistency to feed regularly, and freshened about twice in a week.

Construction of a Breast-Wheel of very great Width.—At Messrs. Strutt's works is a very powerful breast-wheel, made of the extraordinary width of 40 feet, and it deserves our notice from the manner of framing it together; its diameter is only 12½ feet, and it is made without any axis, or rather the axis is hollow, and so large that the float-boards are fixed immediately upon it. It is made like a very long cask, 48 feet long, composed of 32 staves of six inches thickness, bound together by hoops like an ordinary cask; it is five feet in diameter at one end and six feet at the other, and in the middle 7 feet 2 inches; the small end is made up solid for three feet in length, and the gudgeon is fixed in this solid part; the larger end is solid for four feet from the end, and on this part the large cog-wheel is fixed to communicate the motion to the mill; it is 14 feet diameter, and has 120 cogs, whilst the water-wheel is only 12½ feet diameter to the outside of the floats. The floats are supported by 10 circular rings, which are fixed on the outside of the axis or cask, at four feet distance from each other, and the float-boards are fixed between these rings, 24 floats being arranged in each circle; but the floats in the different spaces are not made to line with each other, because if the water was to strike upon the whole length of 40 feet of float-board at once, it would give a sensible shock to the water-wheel, and work the mill irregularly; hence the floats between all the different rings are placed opposite to the intervals between the floats in the adjoining spaces, by which means the water acts on the floats in rapid succession, so that the stroke upon any one float is imperceptible.

The float-boards are not made to touch the central-barrel or axis within two inches, in order to leave space for the air to escape. The float-boards in the middle of the wheel are 2 feet 4 inches wide, and at the ends are wider. This wheel has two shuttles, one above the other, like the breast-wheel before described in *fig. 3*, and the same dimensions; for the wheel is placed in the same mill, but is adapted to work when the tail-water rises in time of floods to such a height as to prevent the other wheel from working.

A very large overshot Wheel.—The largest overshot water-wheel of which we have heard, is that at Mr. Crawshaw's iron-works at Cyfarthfa, near Merthyr Tidvil, in South Wales: it is used to blow air into three of the large blast

furnaces for smelting iron; the water-wheel is fifty feet in diameter and six feet wide: it is chiefly made of cast iron, and has 156 buckets. The axis is a hollow tube, and is strengthened by twenty-four pieces of timber applied round it. On each end of the axis is a cog-wheel of twenty-three feet diameter, which turns a pinion. On the axis of these are two cranks, and a fly-wheel twenty-two feet diameter, and twelve tons weight; each of the cranks gives motion to a lever, like that of a large steam-engine, and works the piston of a blowing cylinder or air-pump 52½ inches in diameter, and five feet stroke, which blows air into the furnace, both when the piston goes up and down. The work on the other side being the same, it actuates in the whole four of these double cylinders; the wheel makes about two and a half turns *per minute*, and each cylinder makes ten strokes. It is called *Æolus*, and was built in 1800 under the direction of Mr. Watkin George.

At Aberdare, in South Wales, is an immense double water-wheel, consisting of two wheels of forty feet in diameter, placed one above the other like the figure 8, (see our article *CANAL*;) the water from the upper one actuating the lower one, and both being connected together by cog-wheels on their respective rings. We understand this machine has not answered, and we only mention it as an attempt to occupy a fall of water of eighty feet; in such cases, the *Pressure-engine*, described under that article, is a better method, particularly if the work will admit of a reciprocating motion.

Chain of Buckets.—This is applicable in many situations where there is a considerable fall of water. This sketch was taken from one in Scotland used to give motion to a thrashing-mill; the *fig. 6. Plate I.* is so obvious as to need little explanation. The buckets C, D, G, H, &c. must be connected by several chains to avoid the danger of breaking, and united into an endless chain, which is extended over two wheels A and B, the upper one being the axis which is to communicate motion to the mill-work; E is the spout to supply the water. The principal advantage of this plan is, that no water is lost by running out of the buckets before they arrive at the lowest part, as is the case with the wheel. Another is, that the buckets being suspended over the wheel A of small diameter, it may be made to revolve more quickly than a wheel of large diameter, and without increasing the velocity of the descending buckets beyond what is proper for them. This saves wheel-work when the machine is to be employed, as in a thrashing machine to produce a rapid motion. On the other hand, the friction of the chain in folding over the wheel at the top, and seizing its cogs, will be very considerable; these cogs must enter the spaces in the open links between the buckets, to prevent the chain slipping upon the upper wheel. We think this machine might be much improved by contriving it so, that the chain would pass through the centre of gravity of each bucket, whereas in the present form, the weight of each bucket tends to give the chain an extra bend.

The *Chain-Pump reversed* has been proposed as a substitute for a water-wheel when the fall is very great, and we think it would answer the purpose with some chance of success. It would have an advantage over the chain-pump when employed for raising water, in the facility of applying cup leathers to the pistons on the chain, in the same way as other pumps, which leathers expand themselves to the inside of the barrel, and are kept perfectly tight by the pressure of the water. In the chain-pump such leathers cannot be employed, because the edges of the leather-cups would turn down and stop the motion, when the cups were drawn upwards into the barrel. It is the defective mode of leathering the pistons of the chain-pump which occasions its great friction. In the motion of a machine of this kind

the pistons would descend into the barrel, and might therefore be leathered with cups like other pumps, so as to be quite tight without immoderate friction. This machine was proposed by a Mr. Cooper in 1784, who obtained a patent for it, and Dr. Robison has again proposed it with recommendation.

Mechanism for equalizing the Motion of Water-Wheels.—When a part of the machinery of a mill is suddenly detached from the first mover, or suddenly connected with it, the load of the machine is either increased or diminished; and the moving power remaining the same, an alteration in the velocity of the whole will take place; it will move faster or slower. Every machine has a certain velocity, at which it will work with greater advantage than at any other speed; hence the change of velocity arising from the above cause, is in all cases a disadvantage, and in delicate operations exceedingly hurtful. In the case of a cotton mill, for instance, which is calculated to move the spindles at a certain rate, if from any cause the velocity is much increased, a loss of work immediately takes place, and an increase of waste from the breaking of the threads, &c.; on the other hand, there must be an evident loss from the machinery moving too slow. In steam-engines this evil is remedied by a contrivance called a governor, which we have already described in our article *STEAM-Engine*.

Governors are sometimes applied to water-wheels, and made on various constructions. Smith-bellows have been applied to that use, the upper board rising and falling on any augmentation or diminution of the velocity of the lower board, which received its motion from the mill, and forced air into the space beneath the upper board; from this space the air was permitted to escape by a pipe with a cock. If the lower board worked faster than the air could escape, the upper board would rise, but if it moved slower, then the board would sink; and this rising and falling was applied to regulate the shuttle of the water-wheel, not by the force of the bellows alone, but the bellows were made to throw the wheel-work of the mill into action, either to raise or lower the shuttle.

Of late years a new kind of water-wheel governor has been introduced, the principles of which are nearly the same as the governor of a steam-engine. It has a revolving pendulum, which receives its motion from the mill, and in proportion as the machinery moves faster or slower, the centrifugal force acts with greater or less force upon the balls of the governor, making them approach to, or recede from, the perpendicular axis. This raises or depresses an iron cross, which slides upon the perpendicular axis of the revolving pendulum, and by acting on a lever, is made to engage the sluice with a train of wheel-work, which is kept in constant motion by the power of the water-wheel. When this train is connected with the sluice, it operates upon it so as to enlarge or lessen the passage of the water to the water-wheel, and by augmenting or lessening the quantity of water falling on the wheel, increases or diminishes its speed.

This sluice is made on the principle of the throttle-valve of steam-engines. In order that it may be moved by a small power, it is poised on an axis of motion passing through the middle of the sluice. When it is turned edgewise to the stream of water, it makes no obstruction; but if it is turned perpendicularly, it closes the passage of water, or by placing it more or less obliquely, it alters the area of the passage for the water.

The axis on which the sluice turns, if horizontal, should be one-third of the height of the sluice from the bottom, in order that the pressure of the water above the centre may balance that below.

So long as the machinery is moving at a proper velocity, this wheel-work of the sluice apparatus is not connected with the sluice, and it remains at rest. But if the mill goes too slow, the cross is depressed, and striking the lever in an opposite direction, connects the sluice with a different part or train of wheel-work, which has a motion in a contrary direction to the former, and so produces a contrary effect on the sluice.

The train of wheel-work is so calculated, as to reduce the action on the sluice to a very slow motion, and it is found, from experience, that this is necessary. Where the area of the aperture is too suddenly changed, the effect on the water-wheel would be too violent. See a more complete description of this contrivance in Vol. XXIII. *MILL-Work*.

On the Construction of the Wheel-race and Water-course.—The wheel-race should always be built in a substantial manner with masonry, and if the stones are set in Roman cement, it will be much better than common mortar. The earth behind the masonry should be very solid, and if it is not naturally so, it should be very hard rammed and puddled, to prevent percolation of the water. This applies more particularly to breast-wheels, in which the water of the dam or reservoir is usually immediately behind the wall or breast in which the wheel works, a sloping apron of earth being laid from the wall in the dam to prevent the water leaking. The wall of the breast should have pile planking (see *CANAL*) driven beneath, to prevent the water from getting beneath, because that might blow up the foundation of the race. The stones of the race are hewn to a mould, and laid in their places with great care; but afterwards when the side walls are finished, and the axis of the wheel placed in its bearings, a gauge is attached to it and swept round in the curve, and by this the breast is dressed smooth, and hewn to an exact arch of a circle: the side walls in like manner are hewn flat and true at the place where the float-boards are to work. It is usual to make the space between the side walls two inches narrower at each side, in the circular part where the floats act, than in the other parts.

In some old mills the breast is made of wood planking, but this method has so little durability that it cannot be recommended. In modern mills, the breast is lined with a cast-iron plate, but we do not approve of this, because it is next to impossible to prevent some small leakage of water through the masonry, and this water being confined behind the iron breast cannot escape, but its hydrostatic pressure to force up the iron is enormous; and if the water can ever insinuate itself behind, the whole surface of the plate rarely fails to break it, if not to blow it up altogether. This is best guarded against by making deep ribs projecting from the back of the plate, and bedding them with great care in the masonry; these not only strengthen the plate, but also cut off the communication of the water, so that it cannot act upon larger surfaces at once, than the strength and weight of the plate can resist. Stone is undoubtedly the best material for a breastling. In overshot-wheels the loss of water, by running out of the buckets as they approach the bottom of the wheel, may be considerably diminished by accurately forming a sweep, or casing round the lower portion of the wheel, so as to prevent the immediate escape of the water, and causing it to act in the manner of a breast-wheel, which has been already described. While this improvement remains in good condition, and the wheel works truly, it produces a very sensible effect; but it is frequently objected to, because a stick or a stone falling into the wheel would be liable to tear off part of its shrouding, and damage the buckets; and again, a hard frost frequently binds all fast, and totally prevents the possibility of working during its continu-

nuance; but we do not think the latter a great objection, for the water is not more liable to freeze there than in the buckets or on the shuttle, and may be prevented by the same means, *viz.* by keeping the wheel always in motion; a very small stream of water left running all night will be sufficient. Mr. Smeaton always used such sweeps, and with very good effect; it is certainly preferable to any intricate work in the form of the buckets.

On setting out Water-courses and Dams.—The most ancient mills were undershot-wheels placed in the current of an open river, the building containing the mill being set upon piles in the river. It would soon be observed that the power of the mill would be greatly increased, if all the water of the river was concentrated to the wheel, by making an obstruction across the river which penned up the water to a required height; and also to form a pool or reservoir of water. A sluice or shuttle would then become necessary to regulate the admission of water to the wheel, and other sluices would be necessary to allow the water to escape in times of floods; for though in ordinary times the water would run over the top of the obstruction or dam, yet a very great body of water running over might carry away the whole work, by washing away the earth at the foot of the dam, and then overturning it into the excavation. This is an accident which frequently happens to mills so situated, and the danger is so obvious, that most water-mills are now removed to the side of the river, and a channel is dug from the river to the mill to supply it with water, and another to return the water from the mill to the river. The difference of level between these two channels is the fall of water to work the mill, and this is kept up by means of a weir or dam entirely across the river; but the water can run freely over this dam in case of floods, without at all affecting the mill, because the entrance to the channel of supply is regulated by sluices and side walls.

The dam should be erected across the river at a broad part, where it will pen up the water so as to form a large pond or reservoir, which is called the mill-pond or dam-head. This reservoir is useful to gather the water which comes down the river in the night, and reserve it for the next day's consumption; or for such mills as do not work incessantly, but which require more water, when they do work, than the ordinary stream of the river can supply in the same time. The larger the surface of the pond is, the more efficient it will be; but depth will not compensate for the want of surface, because as the surface sinks, when the water is drawn off, the fall or descent of the water, and consequently the power of the water, diminishes.

The dam for a large river should be constructed with the utmost solidity; wood framing is very commonly used, but masonry is preferable. Great care must be taken, by driving pile planking under the dam, to intercept all leakage of the water beneath the ground under the dam, as that loosens the earth, and destroys the foundation imperceptibly; when a violent flood may overthrow the whole. It is a common practice to place the dam obliquely across the river, with a view of obtaining a greater length of wall for the water to run over, and consequently prevent its rising to so great a height, in order to give vent to the water of a flood. But this is very objectionable, because the current of water constantly running over the dam, always acts upon the shore or bank of the river at one point, and will in time wear it away, if not prevented by expensive works. This difficulty is obviated, by making the dam in two lengths which meet in an angle $>$, the vertex pointing up the stream. In this way the currents of water, coming from the two opposite parts of the dam, strike together, and

spend their force upon each other, without injuring any part. A still better form is a segment of a circle, which has the additional advantage of strength, because if the abutments at the banks of the river are firm, the whole dam becomes like the arch of a bridge laid down horizontally. This was the form generally used by Mr. Smeaton.

The foot of the dam where the water runs down should be a regular slope, with a curve, so as to lead the water down regularly; and this part should be evenly paved with stone, or planked, to prevent the water from tearing it up, when it moves with a great velocity.

When the fall is considerable, it may be divided into more than one dam; and if the lower dam is made to pen the water upon the foot of the higher dam, then the water running over the higher dam will strike into the water, and lose its force. There is nothing can so soon exhaust the force of rapid currents of water as to fall into other water, because its mechanical force is expended in changing the figure of the water (see *circular weir* in our article CANAL); but when it falls upon stone or wood, its force is not taken away, but only reflected to some other part of the channel, and may be made to act upon such a great extent of surface as to do no very striking injury at any one time, but by degrees it wears away the banks, and requires constant repairs: for it is demonstrable that, as much of the force of the water as is not carried away by the rapid motion with which it flows, after passing the dam, must be expended either in changing the figure of the water, or in washing away the banks, or in the friction of the water running over the bottom.

The cotton-works of Messrs. Strutt at Belper, in Derbyshire, are on a large scale, and the most complete we have ever seen, in their dams and water-works. The mills are turned by the water of the river Derwent, which is very subject to floods. The great weir is a semicircle, built of very substantial masonry, and provided with a pool of water below it, into which the water falls. On one side of the weir are three sluices, each 20 feet wide, which are drawn up in floods, and allow the water to pass sideways into the same pool; and on the opposite side is another such sluice, 12 feet wide. The water is retained in the lower pool by some obstruction which it experiences in running beneath the arches of a bridge; but the principal fall of the water is broken by falling into the water of the pool, beneath the great semicircular weir.

The water which is drawn off from the mill-dam above the weir passes through three sluices, 20 feet wide each, and is then distributed by different channels to the mills, which are situated at the side of the river, and quite secure from all floods. There are six large water-wheels; one of them, which is 40 feet in breadth, we have mentioned, from the ingenuity of its construction; and another which is made in two breadths, of 15 feet each, we have also described. They are all breast-wheels. The iron-works of Messrs. Walker at Rotherham, in Yorkshire, are very good specimens of water-works; as also the Carron works in Scotland.

The largest works for overshot-mills are in Russia, at Culpino, near St. Petersburg, on the river Neva. They were erected principally under the direction of Mr. Gai-coigne of the Carron works in Scotland, and have been greatly improved by the present director, who is an engineer of his school. An immense dam of granite is built across the river to pen up the water, until it makes a large reservoir. The waste and flood waters do not run over this dam, but are conducted out of the reservoir by a semicircular branch of the river, and run over a great weir to join the original course of the river below the works. The

mills are situated in the valley below the great dam, the water being conveyed to the wheels by channels coming through the dam, and conveyed away into a large tail basin, which is the original course of the river. The wheels, which are very numerous, are all 22 feet diameter. They are placed in several different mills, for rolling and forging iron and copper, boring guns, making anchors, &c. These mills are arranged on the sides of the tail basin, which is navigable to bring the boats up to them. There are also two large saw-mills at the end of the semicircular channel.

These works are very complete, owing to the excellent execution of the dam and water-works; but it is not a good plan to place the mills beneath the dam, because if it should fail, or the water pour over it by an extraordinary flood, the mills and buildings below would be in danger of being carried away; whereas, on the other construction, the mills, being placed at a distance from the river, are perfectly safe, and would not be injured if the dam should be wholly carried away. This is not a fault imputable to the gentlemen we have mentioned, as the foundations of these works were commenced in the time of Peter the Great, and too far advanced to admit of altering the plan radically, when the empress Catherine invited Mr. Galkoigne to Russia, in 1786, to enlarge them to their present magnitude.

On the Distribution of the different Falls of Water in Rivers.—In erecting a mill, care must be taken to place it so that it shall not be impeded by flood-waters, except when they rise to excess. When the water below will not run off freely, but stands penned up in the wheel-race, so that the wheel must work or row in it, the wheel is said to be tailed, or to be in back water or tail water.

Upon most rivers in this country all the falls of water are fully occupied, and at every mill there is a weir, which pens up the water as high as the mill above can suffer it to stand without inconvenience. Each miller is anxious to obtain the greatest possible fall, and he can at any time augment the fall, by raising the surface of his weir; but as this may produce an inconvenience to the mill above, in preventing the water from running freely away from its wheel, it is a constant source of dispute and litigation. A mill may be subjected to tail-water by the concurrence of so many circumstances, that it is frequently very difficult to know where to seek the best remedy, whether the miller ought to raise his wheel higher and diminish his own fall, or insist upon a diminution of his neighbour's below him by lowering his weir.

The following rule is that which Mr. Smeaton constantly followed, in placing successive dams upon rivers, whether for the erection of mills or for navigation. In flat countries, where the falls of water are small, and consequently tail or back water is most troublesome, those dams must be so built, that no one shall pen the water into the wheel-race of the mill next above it, when the river is in its ordinary summer's state. The same rule we have found generally subsisting in ancient mills.

This rule is founded upon reason; for if the erection of a dam does not affect the mill above by tail-water, in dry seasons, when water is the most scarce, it can do no material injury at any other time. Every mill that is well and properly constructed will clear itself of a considerable depth of tail-water, provided it has at the time an increase of the height of water in the mill-dam or head, and an unlimited quantity of water to draw upon the wheel; for if floods produce tail-water, they also increase the head water, and afford a superior quantity to be expended. This is the proper means by which a number of mills on the same river are to be cleared of back-water, as far as is consistent with the mutual enjoy-

ment of their several falls of water. This alone is a very sufficient security against any one being injured. Common breast-mills will bear two feet of tail-water, when there is an increase of head, and plenty of water to be drawn upon the wheel, without prejudice to their performance; but mills well constructed, with slow moving wheels, will bear three and even four feet and upwards of tail-water. Mr. Smeaton mentions having seen an instance of six feet; and it is a common thing in level countries, where tail-water is most annoying, to lay the wheels from six to twelve inches below the water's level of the pond below, in order to increase the fall of water; and, if judiciously applied, is attended with good effect, as it increases the diameter of the wheel, and though it must always work in that depth of tail-water, it will perform full as well, because the water ought always to run off from the bottom of the wheel, in the same direction as the wheel turns.

The law respecting mill property is by no means settled, but is greatly influenced by the custom of the mills upon any river or in any district; some few points however are established. Every one has a right to that fall which the water has, in running through his own grounds, and may make what use he pleases of the descent of the water, provided that he does not divert the water, at the tail of his estate, into any other channel, or that he does not pen up the water higher than the level at which it has always entered into his land; he has also a right to insist that the miller below shall let the water depart from his grounds, at the same level at which it has always been used to do. The knowledge of this is very necessary, because a miller very frequently finds himself seriously injured, when he is not entitled to any redress. It scarcely ever happens that any considerable improvements or alteration in mills can be made, without producing disputes among the parties interested. Suppose, for instance, that there are two ancient mills upon a river, with an unoccupied descent in running over the lands between them, the proprietor of this land, by deepening the channel and erecting a weir, may bring all the fall into one place and erect a mill, without infringing the conditions we have laid down; but still the miller below him may be considerably injured: for in the original state the river, in running down with a regular and easy slope, from the upper mill to the lower, held a great quantity of water, which was a *corps de reserve* for the miller below, and tended to regulate his supply. If the upper mill stopped working, the water contained in the river would still run down to him, and so long as that lasted he could continue to work, perhaps until the upper mill began to work again, and thus he would suffer no interruption. The erection of an intermediate mill cuts off this resource, and he will be obliged to stop working very soon after the new mill stops working; and further, he is obliged to work when the new mill is at work, or else the water poured down will run over his mill-dam and be wasted; but, in the former instance, the water would have come down less suddenly, and he might be able to set to work before the whole of the water had escaped over his weir.

In such a case the lower miller may be inclined to appeal to the law, but he will find that he has no right to prevent his neighbour above from using the water in the same manner as he does himself, and if he finds any alteration in his own mill, it is for want of a capacious mill-pond to reserve the water. In the original state the channel of the river in his neighbour's ground above served him in some measure as a mill-dam, by retaining the water for a given time, though it would not retain it permanently. The advantage of this he had enjoyed for a long time, when it was no inconvenience to his neighbour, but had acquired no right to

demand that his neighbour's property should be sacrificed for his convenience, but he must relieve himself by making an artificial pond for his own mill.

The same question arises when any mill is altered or enlarged, so as to consume the water faster than the river brings it down, for such a mill can only work for short intervals, and must then stop that the water may accumulate in the dam until there is a sufficient quantity to set to work again. This is the system of copper-mills and rolling-mills, for during the time that the iron or copper is heating in the

furnace, the mill is stopped, and the water gathered in the dam; but when the metal is ready, it is set to work with all the power of the water penned up. This is very prejudicial to a mill below, particularly if it is a corn-mill, which cannot consume the water faster than the regular supply of the river, and sometimes also to mills above by frequently tailing their water.

Much useful information on these points will be found in Smeaton's Reports, 3 vols. 4to. 1813.

WATER WHEELS. OVER SHOT and UNDER SHOT.

PLATE I.

Fig 2

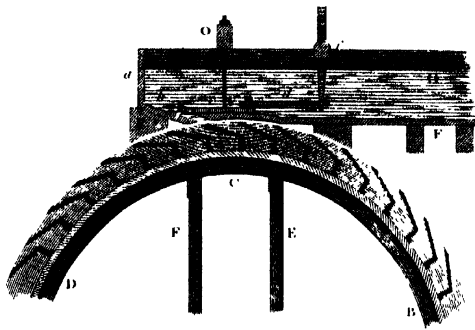
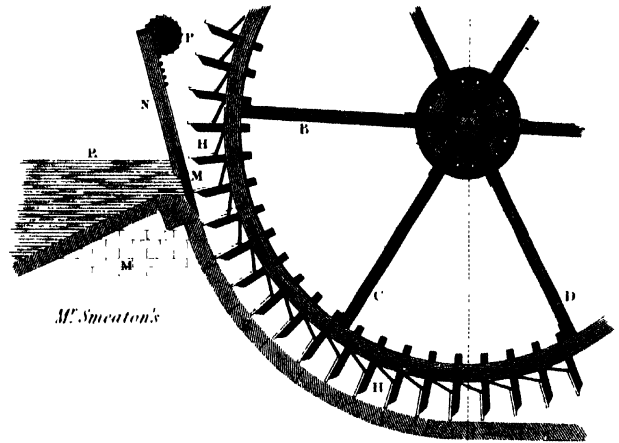


Fig 1



M^r Smeaton's

Fig 4

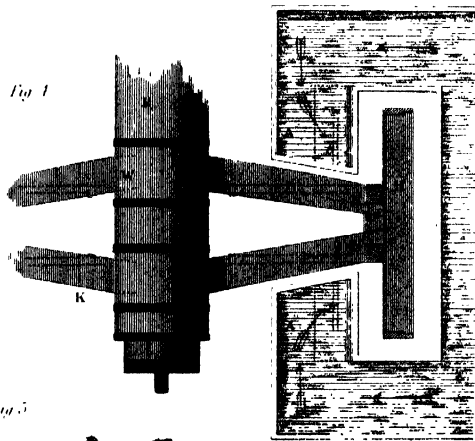
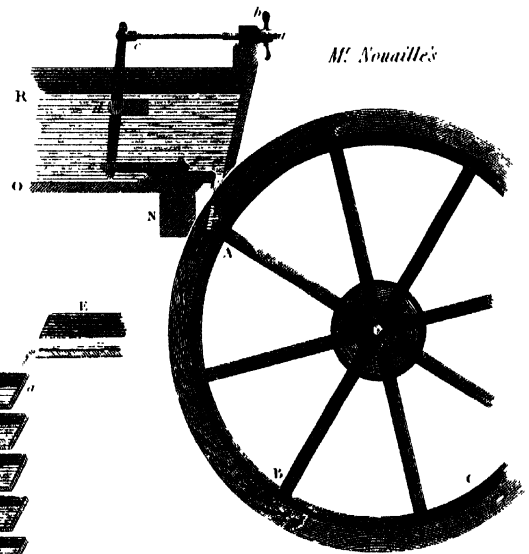


Fig 3



M^r Nouaille's

Fig 5

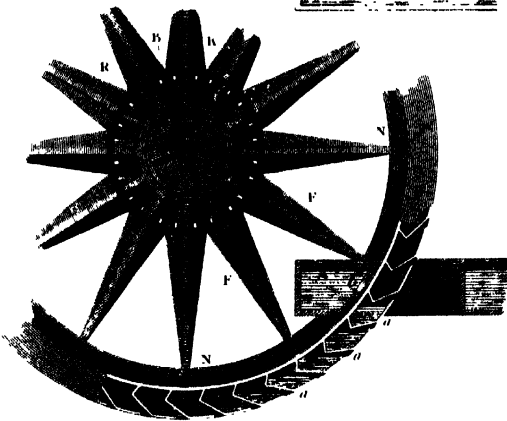


Fig 6

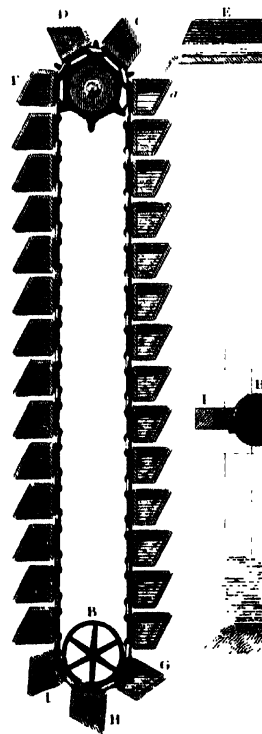


Fig 7

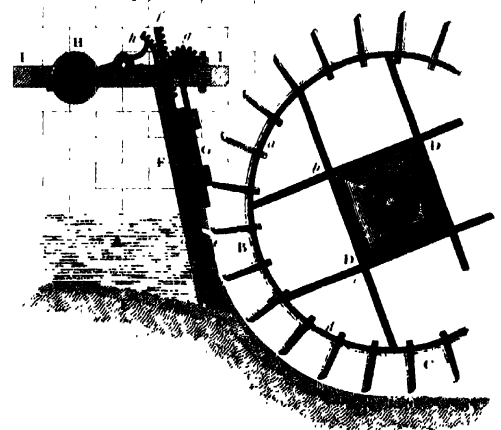
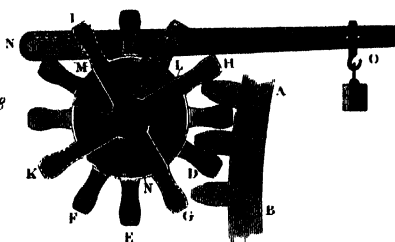


Fig 8



Breast WHEEL with two Shuttles.

Fig 3

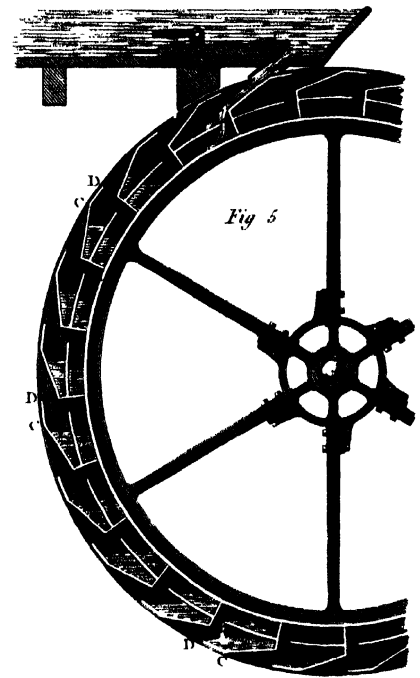
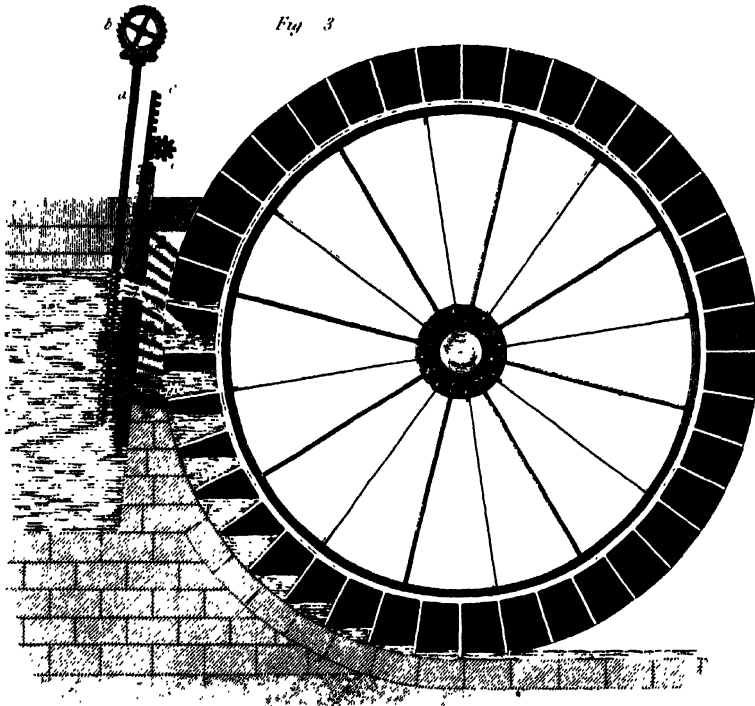
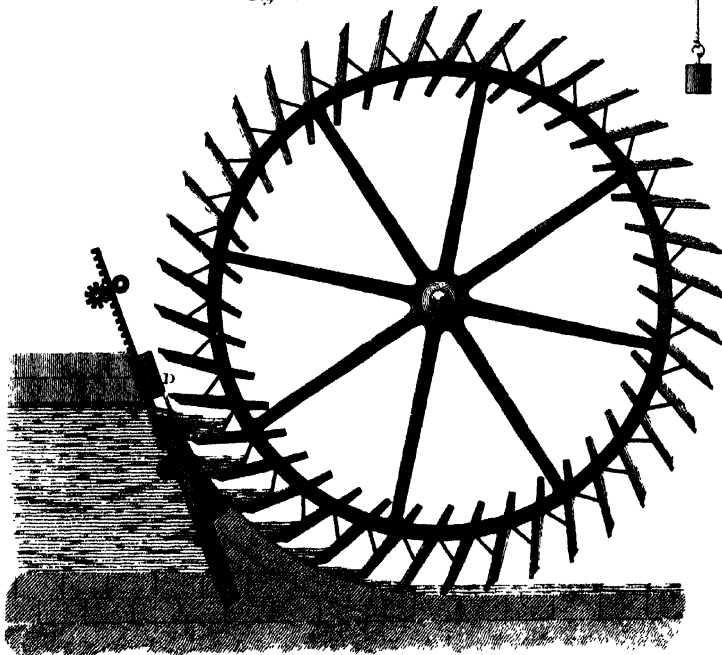


Fig 5

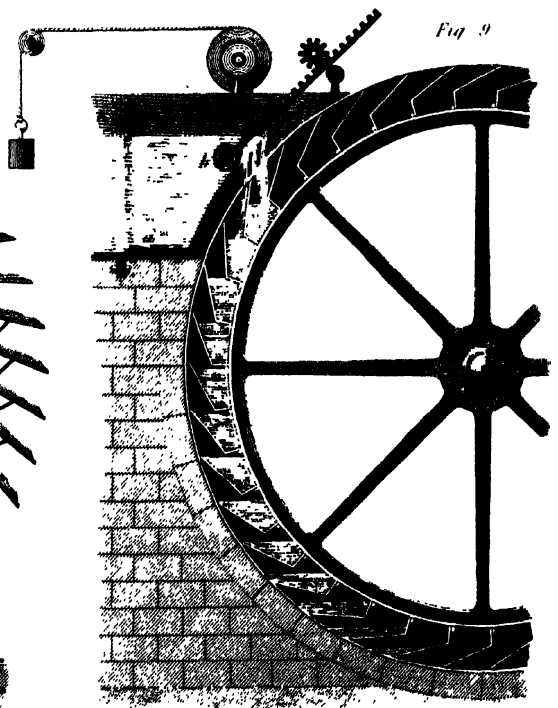
Breast WHEEL in which the water flows over the Shuttle

Fig 4



Overshot WHEEL

Fig 9



Wax

WAX, a term which comprehends two or three substances, differing in their nature and origin, and yet possessing several common properties. The common properties of the animal and vegetable productions, of which we shall give a brief account in the sequel of this article, are fusibility at a moderate heat ; when kindled, burning with much flame ; insolubility in water ; solubility in alkalies, and also in alcohol and ether ; in which two latter properties all the species of wax differ from the concrete oils, to which in other respects they bear a very strong resemblance. The most important, and most generally known and used of these substances, is

Bees'-wax, excreted from the body of the bee, and employed by these insects in the construction of their cells, both for the accommodation of their young and the deposition of their honey. Of this substance, a young hive will yield at the end of the season about a pound of wax ; and an old hive about twice as much. The finest wax is that which is made in dry, heathy, or hilly countries ; but in parts abounding with vineyards it is decidedly inferior. Although the commonly received notion, which ascribes this substance to the elaboration of the pollen of flowers, which the bees visibly collect on their thighs, had received the sanction of observers not less distinguished than Bonnet and Reaumur (see *PAIN D'Abeilles*), yet the Lusatian Society, as long ago as the year 1768, was not unacquainted with the fact, that the wax, instead of being discharged from the mouth, is secreted in the form of thin scales among the abdominal rings or segments. In 1792, the celebrated Mr. John Hunter detected the genuine reservoir of the wax under the belly of the bees, and gave an account of his observations in the *Philosophical Transactions*, (vol. lxxxii. part 1.) On elevating the lower segments, he observed plates of a fusible substance, which he ascertained to be wax ; and he was convinced, that an essential difference subsists between the pollen, which these little creatures collect with so much care and industry in the form of pellets on their thighs, and the matter of which the combs are constructed. This curious subject has been further investigated by Messrs. Huber, father and son ; and they have demonstrated the organs in which the wax is secreted, though they had eluded the perspicuity of Swammerdam, Hunter, and other acute anatomists. These sacklets, or small compartments, now minutely explained and illustrated by engravings, are peculiar to the working bees, which alone produce wax ; and each individual is furnished with eight of them. The waxy matter, as it occurs in a transfused state in the secretory organs, differs from the fresh wax of the combs only in being of a less compounded nature, which has been ascertained by trials with spirit of turpentine and sulphuric ether. Prosecuting these reflections, our ingenious authors concluded that the common opinion was probably erroneous ; because, like Hunter, they had observed swarms, newly placed in the empty hives, construct their combs without fetching home any pollen ; while the bees of old hives, where no fresh cells were required, nevertheless provided an ample stock of this powder. In order, however, to determine the point more directly, they confined a recent swarm within an empty straw-hive, leaving at their disposal only a sufficiency of honey and water for their consumption, and preventing them from going beyond the precincts of a well-closed room ; when, in the short space of five days, they had constructed five cakes of a beautiful white though very fragile wax. This experiment was repeated, and was uniformly accompanied by similar results ; and therefore they no longer hesitated in admitting the fact, that honey, through the organic

intervention of bees, may be converted into wax. In order to determine whether vegetable pollen, also, was susceptible of this conversion, the honey was wholly removed, and the confined bees were fed on fruits and pollen, of which last a large store was left at their disposal ; but, though they continued in this situation during eight days, they neither made any wax, nor exhibited any plates under their abdominal rings. Having suspected that the secretion of wax originated in the cohesive principle contained in honey, our authors resorted to various experiments, which constantly proved that sugar alone was an excellent substitute for honey, and, on some occasions, afforded a superior wax. They afterwards found, that bees, when left at perfect liberty to roam abroad, act precisely on the same principle in the construction of their combs ; and they also discovered, that labourers of two descriptions exist in each hive. The first, susceptible of acquiring considerable dimensions, when they have received all the honey which their stomachs can contain, are principally destined to the elaboration of the wax ; while the second, whose abdomen undergoes no sensible change of bulk, neither gather nor retain more honey than is necessary for immediate subsistence, and readily share that which they collect with their companions ; who take no charge of storing the hive with provisions, their appropriate office being to attend the young. These they call nursing or small bees, in contradistinction to those with dilated bellies, and which, as they say, are entitled to the appellation of "wax-workers." The existence and separate offices of these two sorts of bees were sufficiently ascertained. When the hives are filled with combs, the wax-working bees disgorge their honey into the usual magazines, and produce no more wax ; but, if they have no receptacle in which they can deposit it, and if the queen finds no cells formed ready for the reception of her ova, they retain in their stomachs the honey which they had amassed ; and, at the end of 24 hours, the wax oozes out between the rings, when the fabrication of the combs commences. The nursing bees also produce wax, but in a much smaller quantity than the others.

As for the use of the pollen, our authors have ascertained, that it is collected for the purpose of feeding the young ; and they have also found, that bees, fed too long on the syrup of sugar alone, are incapable of rearing their offspring, and at length desert the hive. The waxy matter, when newly secreted and moulded in its appropriate organs, differs from real wax in being transparent like scales of talc, white, and quite friable, or brittle ; whereas that of which the cells are composed is of a yellowish-white, opaque, and flexible. Our limits will not allow our describing the processes observed by our authors with the aid of a glass apparatus, by which these insects commence and conduct the construction of their combs. The difference of aspect and consistency between cells just formed, and those which are of older standing, cannot fail to attract the attention of every observant apiarian. The former are, in fact, of a dull white colour, semi-transparent, soft, and even, without being smooth ; but, in the course of a few days, the whole of their internal surface assumes a yellow tint of greater or less intensity : their sharp edges become thicker and less regular ; and those tubes, which at first could not resist the slightest pressure, become flexible, somewhat more heavy, and more difficult of solution in hot water. The contour of the orifice of mature cells is bound with a rim of a reddish and odorous resin, which is also employed to cement the angles of other parts of the cell. This folder or varnish is found, on chemical trial, to be identical with the propolis,

and quite distinct from the wax. Messrs. Huber have not only established this important fact, but detected the origin of the propolis itself. Having obtained branches of the wild poplar, cut in spring before the developement of their leaves, with very large buds filled with viscous, reddish, and odorous juice, they placed these in the way of the bees to the fields, so that they must see them: soon after this arrangement, a bee alighted on one of the branches, and approached one of the largest buds; she then separated its folds with her teeth, attacked the parts which she had half-opened, pulled off filaments of the viscid matter with which they were filled, and then seized, with one of the legs of the second pair, the substance held between her jaws, brought forwards one of her hind-legs, and finally placed in the basket of that leg the little ball of propolis which she had just collected. Having accomplished this object, she again opened the bud in another place, carried off new threads of the same matter with her teeth, laid hold of them with the legs of the second pair, and placed them nicely on the other basket. She then took her departure, and rejoined her hive. In a few minutes afterwards, a second bee alighted on the same branches, and loaded herself with propolis in the same manner. This propolis was found to be different from the matter which imparts the yellow colour to the wax, which is probably secreted in the cavity of the teeth, and deposited on the wax. We observe, however, that bees are not contented with merely painting and varnishing their cells, but they also impart additional solidity to their aggregate amount by the use of a mortar, composed of wax and propolis; and which the ancients, who had not overlooked this department of their economy, termed *metis*, or *pissocorum*. (See PROPOLIS.) With the necessary documents before us, we cannot forbear introducing some further observations on the economy of these insects, though they are not immediately connected with the subject of this article. As the closeness of a hive, and the multitude of living creatures which inhabit it, (amounting sometimes to twenty-five or thirty thousand,) are circumstances which seem to preclude a free ventilation and renewal of air, we might be induced to suppose that bees are not endowed with any particular system of respiratory organs, and that they are capable of existing in any atmosphere, however vitiated. As a test of this supposition, our ingenious and persevering authors resorted to various experiments; which incontestably prove, that these insects cannot long exist either in *vacuo*, or in air that is contaminated by noxious gases; that, in short, they breathe like other animals of their class; and that they are speedily deprived of life if the process of respiration be arrested. Yet it results, from eudiometrical trials, that the air of a well-stocked hive is equally pure with that of the atmosphere. It has been ascertained, too, that neither wax nor pollen favours the production of oxygen gas, and that the bees themselves have no internal faculty of generating vital air; since, if that of the atmosphere be entirely excluded, they are observed to perish in the course of a few hours. Our authors, therefore, took an opportunity of examining, whether the industry of these insects presented no particular cause of this phenomenon; and at length they were struck by the connection which might subsist between the circulation of the air and that beating of the wings which they had recently observed, and which occasioned a continual humming in the interior of their habitation. They suspected that the play of these membranes, which impress the air with sufficient force to elicit from it a very distinct sound, might be destined to replace that which had been vitiated by respiration. Although this may seem to be a trivial cause for counteracting the pernicious effect

above stated, yet by putting the hand near to a fanning-bee, we shall perceive that she agitates the air in a manner that is very sensible, and moves her wings with such rapidity as that they are scarcely distinguishable.

United at their edge by means of small hooks, the two wings of each side present a larger surface to the air, on which they have to strike; they form, besides, a slight concavity, which should somewhat contribute to increase their energy; and we may be satisfied that they describe an arc of 90°, because we see them, simultaneously, on the two extremes of their vibrations. When engaged in this exercise, the bees cling fast to the stand with their legs, the first pair being projected forwards, the second separated and fixed to the right and left of the body, while the third, closely approximated, and in a direction perpendicular to the abdomen, contributes to support the hinder parts in an elevated position. During the fine season, we may always observe a certain number of bees agitating their wings in front of the entrance to their hive; but we may also be convinced, by inspection, that still more of them are employed in fanning within their dwelling. The ordinary station of the ventilating bees is on the lower floor of the hive. All those which are occupied in this way, on the outside, have their heads turned towards the entrance, but those within present their backs to it. These bees seem to arrange themselves methodically, so that they may manage the ventilating process with the greatest ease; being distributed into files, which terminate at the entrance of the hive, and are sometimes disposed like so many diverging rays; but this order is not uniform: and it is probably owing to the necessity to which the fanning bees are subjected of leaving room for such as go and come, whose rapid course constrains them to form in file, that they may avoid being jostled and overturned at every instant. More than 20 bees may sometimes be seen ventilating in the lower part of the hive; but their number at other times is smaller; and each of them vibrates her wings for a longer or shorter period. They have been observed to continue the exertion during 25 minutes, without resting; although they seemed occasionally to take breath by suspending the vibration of their wings for an almost imperceptible instant; but, as soon as they cease from fanning, others take their place, so that the humming noise in a well-filled hive never suffers interruption.

But to return from this digression to the principal subject of the article.

Bees'-wax makes a very considerable article in commerce; the consumption of it throughout the several parts of Europe being incredible. There are two kinds, *white* and *yellow*; the yellow is the native wax, just as it comes out of the hive, after expressing the honey, &c. This colour, says Thorley, is owing to the age of the combs, and breath of the bees; wax, he says, both as it is gathered, and wrought into combs, being always white: the white is the same wax, only purified, washed, and exposed to the air. The preparation of each follows.

WAX, Yellow. To procure the wax from the combs for use; after separating the honey from them as much as possible by the press, they are either soaked for some days in clear water, in order to extract all the honey, or they are broken into pieces, and spread on a sheet near the hives, so that the bees in time suck out all the honey that is left, and reduce the wax into small fragments like bran. Then the whole of the wax is put into a large kettle, with a sufficient quantity of water; and with a moderate fire, it is melted, and then strained through a linen cloth, by a press, and thus freed from all remaining impurity. Before it is cold, they seum it with a tile, or a piece of wet wood, and cast it,

while yet warm, in wooden, earthen, or metalline moulds; having first anointed them with honey, oil, or water, to prevent the wax from sticking. Some, to purify it, make use of Roman vitriol, or copperas; but the true secret is to melt, scum it, &c. properly, without any ingredients at all.

The best is that of a high colour, an agreeable smell, somewhat resembling that of honey, soft, somewhat unctuous to the touch, but not sticking to the fingers, nor to the teeth when chewed. When new, it is of a lively yellow colour; it is somewhat tough, yet easy to break; by age, it loses its fine colour, and becomes harder and more brittle. In winter it becomes considerably hard and tough. It is deprived of its yellow colour and smell by exposing it in thin laminæ to the action of the light and air, in the process of bleaching; by which it becomes perfectly white, scentless, somewhat harder, and less greasy to the touch. However, wax is often sophisticated with resin, or pitch, coloured rocou, or turmeric.

The presence of resin may be suspected when the fracture appears smooth and shining, instead of being granulated: and it may be saturated by putting small pieces of the wax into cold alcohol, which will readily dissolve the resinous part, without affecting the wax in any considerable degree.

Its adulteration with earth or peas meal may be suspected when the cake is very brittle, and the colour inclining more to grey than bright pale yellow; and they may be separated by smelting and straining the wax. White wax is sometimes adulterated with white oxyd of lead, in order to increase its weight. This may be known by melting the wax in water, when the oxyd falls to the bottom of the vessel.

It is also adulterated by tallow, suet, or any kind of animal fat. It then becomes more fusible, and when rebleached and exposed to a hot sun, it is very apt to cake. It likewise loses its semi-transparency, the distinguishing property of pure bleached wax. This adulteration may be detected by boiling alcohol, which will dissolve wax, but not tallow.

WAX, White. The whitening, blanching, or bleaching of wax, is performed by reducing the yellow sort, first, into little bits or grains, and melting it in a copper cauldron, with water just sufficient to prevent the wax from burning. The cauldron in which the wax is melted is so disposed, that it may flow gradually through a pipe at the bottom into a large tub filled with water, and covered with a thick cloth, to preserve the heat till the water and impurities are settled. From this tub the clear melted wax flows into a vessel, the bottom of which is full of small holes, about the size of a grain of wheat, and hence it falls in small streams upon a cylinder, constantly revolving over water, into which it occasionally dips, so that the wax is cooled, and at the same time drawn out into thin shreds or ribbands. The continual rotation of the cylinder carries off these ribbands as fast as they are formed, and distributes them through the tub. The wax, thus granulated or flatted, is exposed to the air on linen cloths, stretched on large frames, about a foot or two above the ground, in which situation it remains night and day for several days, exposed to the air and sun; and thus the yellow colour nearly disappears. In this half-bleached state, it is heaped up in a solid mass, and allowed to remain for a month or six weeks; after which, to complete the process for whitening it, it is re-melted, and ribbanded, and bleached as before, (in some cases several times) till it wholly loses its colour and smell. Some manufacturers, in re-melting it, add alum or cream of tartar, which are supposed to increase the whiteness and solidity of the wax. Some also, instead of spreading the ribbands of wax on

cloths, lay evenly a broad course of bricks, which are frequently watered, so that the wax is kept from melting by the sun's heat absorbed by the bricks.

When the sun and air have at length perfectly blanched the wax, some melt it for the last time in a large kettle; out of which they cast it, with a ladle, upon a table, covered over with little round dents or cavities, of the form of the cakes of white wax, as sold by the apothecaries, &c. having first wetted those moulds with cold water, that the wax may be the more easily got out. Lastly, they lay out these cakes to the air for two days and two nights, to render it more transparent and dry.

As the volatile sulphureous acid has the property of destroying more quickly almost all the colours of vegetables, it has been suggested by Macquer, the author of the *Chemical Dictionary*, that this bleaching might perhaps be shortened, by exposing ribbands of yellow wax to the vapour of sulphur, as is practised for wool and silk; but this process has not been found to succeed.

However, the operation of bleaching wax above described can be performed well only in fine weather, as it depends chiefly on the action of the sun. This circumstance being attended with much inconvenience to the manufacturers, the discovery of a method of whitening wax independently of the seasons would be very useful, and has been recommended to the attention of chemists by some economical societies.

With a view to discover such a method, Mr. Beckman has made experiments, an account of which is published in the fifth volume of the "*Novi Commentarii Societatis Regiæ Scientiarum Gottingensis*." According to these experiments, thin pieces of yellow wax were whitened and hardened, by being digested and boiled in diluted and undiluted nitrous acid, in a few hours. But the wax thus whitened, being melted by means of boiling water, was observed to acquire a yellow colour, less intense, however, than it was before it had been treated with the mineral acids. The marine and vitriolic acids were less effectual than the nitric or nitro-muriatic. He exposed wax to the flames of burning sulphur, but without success. Yellow wax being melted in vinegar, was rendered of a grey colour. The oil of tartar whitened wax, but less effectually than acids had done; and this wax being washed in water, and afterwards digested in nitrous acid, was rendered still more white; but upon melting it in water, a yellowish tinge returned. He liquefied wax in solutions of nitre and alum, but without any good effect. Spirit of wine, which is recommended by Mr. Boyle for this purpose, did indeed whiten the wax, but changed it to a butyraceous substance, so frothy, that its bulk was increased thirty times. Reflecting that tartar is purified from its oily particles by means of a calcareous earth, he tried the effects of a kind of fuller's earth, which he threw upon wax liquefied in water, and he agitated the mixture. This method rendered wax of a greyish colour, and is, therefore, recommended by him as preparatory to bleaching; the time necessary for which, he thinks, may be thus greatly shortened.

M. Sennebier made some remarks on the effect of light, and other supposed discolouring agents. Some yellow wax was melted, and thinly spread upon a plate of glass; and a similar plate was laid upon it when hot; and the edges of the plates were clofed with sealing-wax. Thus the bees'-wax was deprived of the access of air, and it was placed in the sun, to the light of which it was exposed for four or five hours daily. Another quantity of wax was inclosed between plates in a like manner, but kept in the dark. In two days the wax exposed to the sun began to bleach, and

in a month's time the whole, when it did not exceed one-sixth of an inch in thickness, was quite white; whilst no change at all took place in that which was kept in darkness.

Alcohol has no sensible action on wax when cold, but if the fluid be boiled, it will dissolve rather less than one-twentieth of its weight of wax; and the greater part of it separates, when cold, in the form of white bulky flocculi, while the small quantity that remains is wholly precipitated by water. Such is the result of Pearson's and Bostock's experiments; whereas Fourcroy, Chaptal, and Nicholson assert, that it is insoluble in this fluid. Sulphuric ether dissolves wax when heated, and much more copiously than alcohol dissolves it, but the greater part, like that of the former, is separated by cooling, and the remainder by water. Wax boiled in caustic potash makes the fluid turbid, and in process of time rises to the surface in a flocculent form. The portion of the wax, held in solution by the clear alkaline liquor, may be separated by an acid, and the residue floating on the surface is so far converted into a saponaceous state as to have lost its inflammability, and to be no less soluble in pure water than white soap, and again precipitable by acids nearly in its original form, with a restoration of its inflammability. Pure ammonia nearly resembles the fixed alkalies in its action; but the resulting saponaceous form is less soluble in water.

When yellow wax has been long swimming in a solution of carbonate of potash, it becomes grey; and this colour is entirely changed into a milk white by subsequent digestion in nitric acid, and the wax resumes its whiteness.

If wax be distilled with a heat greater than that of boiling water, it may be decomposed. By this distillation, a small quantity of water is first separated from the wax, and then some very volatile and penetrating acid, (probably a modification of the acetous,) accompanied with a small quantity of a very fluid and very odoriferous oil. As the distillation advances, the acid becomes more and more strong, and the oil more and more thick, till its consistence be such, that it becomes solid in the receiver, and is then called *butter of wax*. When the distillation is finished, nothing remains but a small quantity of coal, which is almost incombustible, from the want of some saline matter. Wax cannot be kindled, unless it be previously heated, and reduced into vapours; in which respect it resembles fat oils. The oil and butter of wax may, by repeated distillations, be attenuated, and rendered more and more fluid, because some portion of acid is thereby separated from these substances; which effect is similar to what happens in the distillation of other oils and oily concretes; but this remarkable effect attends the repeated distillation of oil and butter of wax, that they become more and more soluble in spirit of wine; and that they never acquire greater consistence by the evaporation of their more fluid parts. Boerhaave kept butter of wax in a glass vessel open, or carelessly closed, during twenty years, without acquiring a more solid consistence. Wax, its butter, and its oil, differ entirely from essential oils and resins, in all the above-mentioned properties; and in all these perfectly resemble sweet oils. Hence Macquer concludes, that wax only resembles resins in being an oil rendered concrete by an acid; but that it differs essentially from these in the kind of oil, which in resins is of the nature of essential oils; while in wax and other analogous oily concretions, it is of the nature of sweet, unctuous oils, that are not aromatic, and not volatile, and are not obtained from vegetables by expression.

Although wax is not dissoluble at all in watery liquors,

yet the gelatinous solution obtained by boiling it in spirit of wine, by mixture with a thick mucilage of gum arabic, becomes soluble in water, so as to form therewith an emulsion or milky liquor: the wax itself is made in like manner soluble, without the intervention of spirit, by thoroughly mixing it with the gum in fine powder; but when thus dissolved, it proves still insipid, and perfectly void of acrimony.

Wax is soluble abundantly in the fixed oils, and melted with them, produces an uniform mass, the consistence of which, whatever be the proportion of each, is intermediate between the two. It is dissolved but sparingly in essential oils.

Bleached wax burns with a very pure white light, without any offensive smell, and with much less smoke than tallow; and as it is less fusible than tallow, it requires a smaller wick. (See *CANDLES*.) Bleached wax melts at about 155° of Fahrenheit; and the unbleached at 142° , according to Pearson and Nicholson, and also Dr. Bostock, but at 117° according to Fourcroy; whilst tallow melts at 92° , spermaceti at 133° , adipocire at 127° , and the pelu of the Chinese at 145° . (See Nicholson's Journal, vol. i. p. 70, 4to.) The specific gravity is less than that of water, being about .96.

The yellow wax is brought to market in round cakes about two inches thick; and large quantities of it are imported, from the Baltic, the Levant, and the Barbary coast.

The white wax is used in the manufacture of candles, torches, tapers, figures, and a variety of other wax-works. See *CANDLES*, &c.

It is also an article of the *Materia Medica*, and used as an ingredient, partly for giving the requisite consistence to other ingredients, and partly on account of its own emollient quality, in plasters, cerates, and divers pomatums and unguents for the complexion.

The yellow sort, dissolved into an emulsion, or mixed with spermaceti, oil of almonds, conserve of roses, &c. into the form of an electuary; or divided, by stirring into it, when melted over a gentle fire, as much as it will take up of powdery matter, as the compound crab's-claw powder, has been given also internally, and, as some have pretended, often with great success, in diarrhoeas and dysenteries, for obtunding the acrimony of the humours, supplying the natural mucus of the intestines, and healing their excoriations or erosions.

The empyreumatic oil, into which wax is resolved by distillation with a strong heat, is greatly recommended by Boerhaave and others, for healing chaps and roughness of the skin, for discussing chilblains, and with proper fomentations and exercise, against stiffness of the joints, and contractions of the tendons. It is, without doubt, says Dr. Lewis, highly emollient; but does not appear to have any other quality by which it can act in external applications; it has nothing of the acrimony or pungency which prevail in all the other known distilled vegetable oils; though in smell it is not a little disagreeable and empyreumatic; a circumstance which occasions it to be at present more rarely used than formerly. As the wax swells up greatly in the distillation, it is convenient to divide it, by melting it with twice its weight of sand; or putting the sand above it in the retort, that it may mingle with the wax when brought into fusion. The oil, which is preceded by a small quantity of acid liquor, congeals in the neck of the retort, from whence it may be melted down, by applying a live coal, and made fluid by redistilling it two or three times without addition. The feces remaining, after expressing the wax, have been

used both by surgeons and farriers, with success, against strains.

The official preparations are as follow: *cera flava purificata* of Dub. Ph.; *oxidum antimonii vitrificatum* *cera* of Edinb.; *emplastrum cere* of Lond. and Edinb.; *emplastrum cumini* of Lond.; *empl. picis compositum* of Lond.; *empl. oxidi ferri rubri* of Edinb.; *empl. affatida* of Edinb.; *empl. gummosum* of Edinb.; *empl. melos vesicatorii* of Edinb. and Lond.; *empl. galbani* of Dub.; *empl. aromaticum* of Dub.; *ceratum* of Lond. and Dub.; *ceratum calamine* of Lond. and Dub.; *ceratum refine* of Lond. Edinb. and Dub.; *ceratum sabine* of Lond. and Dub.; *ceratum saponis* of Lond.; *unguentum picis aride* of Lond. and Edinb.; *ung. infusi melos vesicatorii* of Edinb.; and *ung. cantharidis* of Dub. Ph. For the first, see *white-wax* below. The second, or vitrified oxyd of antimony with wax, formerly waxed glass of antimony, is formed by melting one part of yellow wax in an iron vessel, and throwing into it eight parts of oxyd of antimony vitrified with sulphur, reduced to powder, and roasting the mixture with a gentle fire for a quarter of an hour, stirring it assiduously with a spatula; then pouring out the latter, and when cold rubbing it into a powder. This preparation is diaphoretic and cathartic, occasionally exciting nausea and vomiting. It was formerly thought to possess efficacy in diarrhoea and dysentery; but is now scarcely ever prescribed. The dose may be from gr. ij. to gr. xv. given twice or three times a day. For the *empl. cere*, see *Wax PLASTER*. For the 4th, see *EMPLASTRUM ϵ Cymino*. For the 5th, see *Compound Pitch PLASTER*. For the 6th, see *PLASTER of red Oxyd of Iron*. For the 7th, see *Affa Fatida PLASTER*. For the 8th, see *Gum PLASTER*. For the 9th, 10th, and 11th, see *PLASTER*. For the others, comprehending *cerates* and *ointments*. See *UNGUENTUM*.

The *bleached* or *white wax* is generally melted and cast, in the manner already stated, into thin discs, about 5 inches in diameter, in which form it is found in the shops. For medical purposes, it is regarded as a demulcent; and has been sometimes administered in obstinate cases of diarrhoea and dysentery, with the view of sheathing the bowels; which effect is better produced by simple mucilages and solutions. It is generally exhibited diffused in mucilaginous fluids by means of soap, in the proportion of 3d part of the wax, with which it is first melted, and then rubbed in a mortar, with the fluid gradually added; but a preferable method is said to be that of Poerner, which is first to melt the wax with olive oil, and then mix the oily compound while hot with the mucilaginous fluid, by triturating with the yolk of an egg. The dose is a cupfull of the emulsion, containing about 3j of wax, given every four or five hours. This wax, as well as the yellow sort, is much used in the composition of plasters and ointments. The official preparations are *ceratum cetacei* of Lond. Edinb. and Dub. pharmacopœias; *unguentum cetacei* of Lond. and Dub.; *ung. hydrargyri nitrico-oxydi* of Lond.; *linimentum simplex* of Edinb.; and *ung. simplex* of Edinb. See *CERATUM*, *LINIMENT*, and *UNGUENT*. Lewis's Mat. Med.

Yellow wax is made soft with turpentine, yet retains its natural colour. Red wax is only the white melted with turpentine, and reddened with vermilion or alkanet. Verdigrise makes it green; and burnt paper, or lamp-black, black. Some travellers tell us of a natural black wax; assuring us there are bees, both in the East and West Indies, that make an excellent honey, included in black cells. Of this wax, they say, it is, that the Indians make those little vases, in which they gather their balsam of Tolu.

WAX is also produced by the secretion of many plants,

and forms the silvery powder or bloom, which covers their leaves and fruit. It is found very abundantly combined with resin, covering the trunk of the wax-palm (*Ceroxylon*) of South America, found in the Quinoliu mountains, 180 feet high, with leaves 20 feet long, the trunk of which is covered with the waxy secretion about two inches thick, and consisting of two-thirds of resin and one of wax; and very pure, encrusting the seeds of the *Myrica cerifera*, or wax-tree of Louisiana, and other parts of North America. The *Pe-la* of the Chinese is an animal wax, and the white lac of India appears to be a variety of wax; so that wax may be regarded, in the extended meaning of the term, both as an animal and a vegetable product. The croton sebiferum, the tomex sebifera, the poplar, the alder, the pine, as well as the *Myrica*, afford a concrete inflammable matter by decoction, that more or less resembles tallow or wax, that is, a fixed oil saturated with oxygen. But the *Myrica cerifera* supplies it in the greatest abundance. The grains of this tree, and the shining wax obtained by boiling them in water, have been long ago, viz. in 1722 and 1725, noticed in the History of the Academy of Sciences. The wax, it was observed, is drier and more friable than ours; and it was found, that the liquor in which the grain had been boiled, and from which the wax was procured, afforded, on evaporation, a kind of extract that checked the most obstinate dysenteries; and the inhabitants of Louisiana are said to have made candles of the wax. Several authors have mentioned different species of these trees; but the wax they afford has more lately been the subject of experimental investigation, particularly by M. Cadet and Dr. Bostock. The most fertile of these shrubs afford near seven pounds of berries, the gathering of which employ several families. These berries are thrown into a kettle, and covered with water. Whilst the water is boiling, the grains are stirred about against the sides of the vessel, so that the wax may more easily come off. In a little time it floats on the water like fat, and being collected, is strained through a coarse cloth, to free it from any impurities. This operation is repeated with fresh berries; and when a considerable quantity of wax has been obtained, it is laid upon a cloth to drain off the water; and it is then dried and melted a second time; and when thus purified, formed into masses. Four pounds of berries afford about one of wax: that which is first obtained is generally yellow; but in the latter boilings it assumes a green colour, from the pellicle with which the kernel of the berry is covered. M. Cadet made a variety of experiments on these berries, and found that the powder which was obtained from them afforded an astringent solution by alcohol, and that it contained gallic acid, but no tannin; and to this acid he attributes their effect in dysenteries. The wax, obtained either by the decoction of the grains, or the solution of the powder when precipitated from alcohol by water, when melted, is always of a greenish-yellow; of a firmer consistence than bees'-wax, dry, and sufficiently friable to be pulverized; and evidently more oxygenated than the wax prepared by bees. Candles made of this wax yielded a white flame, a good light, without smoke, and without guttering; and when quite fresh, they emit a balsamic odour, considered in Louisiana as very salubrious to persons in bad health. Distilled in a retort, this wax, for the most part, passes over in the form of butter. This portion is much whiter, and has no more consistence than tallow. Another portion that was decomposed afforded a little water, with some empyreumatic oil and sebatic acid. Much carbonated hydrogen gas and carbonic acid gas were disengaged; and there remained in the retort a black and coaly bitumen. Ether was found to dissolve

this wax better than alcohol. Oxygenated muriatic acid rendered this, as well as bees'-wax, perfectly white; but the vegetable wax was bleached with the greatest difficulty. The solution in ammonia is of a brown colour, and a portion of the wax is rendered soapy; and it forms soap with fixed alkali. When the soap of *Myrica* is decomposed, a very white wax is obtained, but in a state unfit for our uses. Litharge dissolves very well in this melted wax, and forms a hard plaster, the consistence of which may be diminished at pleasure by the addition of a little oil. For bleaching this wax, M. Cadet observes, that two re-agents present themselves to manufacturers, the sulphuric acid and the oxygenated muriatic acid. He proposes the following method as the most speedy in its effect:—Let the wax be reduced to a very divided state, and stratified in a cask with super-oxygenated muriate of lime, and let them remain for some time in contact without water. Let the salt be afterwards decomposed with water, acidulated by the sulphuric acid; taking care to pour the water a little at a time at different intervals, until there shall be no longer any perceptible disengagement of muriatic gas; at which period a large quantity of water is to be added, and the mixture agitated with a staff. The insoluble sulphate of lime falls down by repose, while the bleached wax rises and swims at the surface. This is to be washed and melted on the water bath. Our author closes his memoir with recommending the culture of the plant that yields this wax, and with a brief detail of methods for effecting this purpose. Dr. Bostock has also prosecuted an inquiry into the nature and uses of myrtle wax. He finds that in its more important properties it resembles bees'-wax, but that in some respects they differ from one another. The myrtle wax is moderately hard and consistent, possessing in part the tenacity of bees'-wax, without its unctuousity, and also, in some degree, the brittleness of resin. The prevalent colour is pale green, tending in moist of the pieces to a dirty grey; in others it is lighter, more transparent, and of a yellowish tinge. Its specific gravity is about 1.0150, water being 1.000, so that it sinks in it, and the white bees'-wax being .9600. Water has no action upon it, either when cold or at the boiling heat. Alcohol, when cold, does not affect it; but 100 parts, by weight, of this fluid, when boiling, dissolve about five parts of the wax. Nearly four-fifths are deposited by the cooling of the alcohol; one-fifth remains suspended, but in the course of a few days is slowly deposited, or may be precipitated by the addition of water. Sulphuric ether, when at the common temperature of the atmosphere, dissolves only a small quantity of this wax, but acts upon it rapidly when boiling. It takes up somewhat more than one-fourth of its own weight. As the ether cools, it is mostly separated, and the small residue may be precipitated by water. After solution, the wax is nearly colourless, and the fluid assumes a beautiful green hue. The deposit by evaporation somewhat resembles spermaceti. Rectified oil of turpentine, at the temperature of the atmosphere, softens the wax, but does not dissolve it: aided by a moderate heat, 100 grains of the turpentine dissolves six grains of the wax. The turpentine acquires a light green tinge, part of the wax is separated as the fluid cools, and part remains permanently dissolved in it. Pure potash renders it colourless by boiling, and forms a soap with a small part, which being decomposed by acid, affords the wax nearly unchanged. Pure ammonia acts nearly as potash, but more feebly. The three principal mineral acids act upon the myrtle wax, but with no great force. The sulphuric acid, with a moderate heat, dissolves about one-twelfth of its weight, and converts it into a thick, dark-brown mass, which on cooling becomes nearly con-

crete, but without any separation of the wax. The nitric and muriatic acids, even when heated, seem to possess little attraction for the wax. From such experiments, Dr. Bostock assigns to myrtle wax, with a considerable degree of probability, the place which it should occupy among chemical substances. Its inflammability, fusibility, insolubility in water, and the action which takes place between it and the alkalies, indicate its affinity to the fixed oils; while its texture and consistence, and more particularly its habitudes with alcohol and ether, manifest a resemblance to the resins. Upon the whole, we may consider the myrtle wax as a fixed vegetable oil, rendered concrete by the addition of a quantity of oxygen; and seeming to hold the same relation to the fixed, which resins do to the essential oils of vegetables. Dr. Bostock has instituted a comparison between myrtle wax and other substances which it resembles, such as bees'-wax, spermaceti, adipocire, and the crystalline matter of biliary calculi; and, upon the whole, deduces this conclusion, that though these five substances possess certain properties in common, and have a degree of similarity in their external appearance, yet that they differ materially in their chemical nature. There is indeed, he says, reason to conjecture, that they are all composed of the same elements, combined together in different proportions, and with different degrees of attraction. *Nicholson's Journal*, vol. iv. 8vo.

WAX, *Chafe*. See CHAFE.

WAX, *Crude* or *Rough*, called by the French *cire brute*, in *Natural History*, a name given to a substance called by the ancients *erithace*, *jandarac*, and *ambrosia*.

We seem to have no name for it in English, but may call it after the name of the French, *rough wax*.

The Dutch call it the food of the bees, and that, perhaps, very properly, there appearing many reasons to think that the bees eat it.

This is the yellow substance found on the hinder legs of bees in small lumps, of which, as Reaumur and some others erroneously thought, wax is made by this insect. See *PAIN d'Abeilles*.

WAX, *Myrtle*. See MYRICA, and WAX, *supra*.

WAX, *Virgin*, *Propolis*, is a sort of reddish wax, used by the bees to stop up the clefts or holes of the hive. It is applied just as taken out of the hive, without any art, or preparation of boiling, &c. It is the most tenacious of any, and is held good for the nerves. See *PROPOLIS*.

WAX, *Sealing*, or *Spanish Wax*, is a composition of gum lacca, melted and prepared with resins, and coloured with some suitable pigment.

There are two kinds of sealing-wax in use: the one hard, intended for sealing letters, and other such purposes, where only a thin body can be allowed; the other soft, designed for receiving the impressions of seals of office to charters, patents, and such written instruments.

The best hard red sealing-wax is made by mixing two parts of shell-lac, well powdered, and resin and vermilion, powdered, of each one part, and melting this combined powder over a gentle fire; and when the ingredients seem thoroughly incorporated, working the wax into sticks. Seed-lac may be substituted for the shell-lac; and instead of resin, boiled Venice turpentine may be used. A coarser, hard, red sealing-wax may be made, by mixing two parts of resin, and of shell-lac, vermilion and red-lead, mixed in the proportion of one part of the vermilion to two of the red-lead, of each one part; and proceeding, as in the former preparation. For a cheaper kind, the vermilion may be omitted, and the shell-lac also, for very coarse uses. The hard black sealing-wax may be prepared in the same manner;

using for the best sort, instead of the vermilion, the best ivory black; and for the coarser sort, instead of the vermilion and red-lead, the common ivory black. For hard green sealing-wax, instead of vermilion, use powdered verdigrise; and for a bright colour, distilled, or crystals of verdigrise. For hard blue sealing-wax, instead of the vermilion, substitute well powdered smalt, or for a light blue, verditer; or a mixture of both. For yellow hard sealing-wax, substitute masticot, or, for a bright colour, turbith mineral, instead of the vermilion. The hard purple wax is made like the red; changing half the quantity of the vermilion for an equal, or greater proportion of smalt, as the purple is desired to be more blue or more red.

For uncoloured soft sealing-wax, take of bees'-wax, one pound; of turpentine, three ounces; and of olive oil, one ounce; place them in a proper vessel over the fire, and let them boil for some time; and the wax will be then fit to be formed into rolls or cakes for use. For red, black, green, blue, yellow, and purple soft sealing-wax, add to the preceding composition, while boiling, an ounce or more of any ingredients directed above for colouring the hard sealing-wax, and stir the mass, till the colouring ingredient be incorporated with the wax.

The hard sealing-wax is formed into sticks, by rolling the mass on a copper-plate, or stone, with a rolling-board, lined with copper, or block-tin, into rolls of any required

size. In order to give them the fire-polish, or gloss, a furnace or stove, like a pail, with bars at the bottom for supporting the charcoal, and notches at the top of the sides for putting the sticks of wax over the fire, is usually provided. By means of this stove the sticks of wax may be conveniently exposed to the fire, and turned about, till the wax is so melted on the surface as to become smooth and shining. Hard sealing-wax may be formed into balls, by putting a proper quantity on the plate or stone, and having fashioned it into a round form, rolling it with the board till it be smooth.

The soft wax is easily formed into rolls or cakes, by pouring the melted mass of the ingredients, as soon as they are duly prepared, into cold water, and working it with the hands into any desired figure. Some perfume both these kinds of wax, by using, for a pound of the wax, half an ounce of benjamin, one scruple of oil of Rhodium, ten grains of musk, and of civet and ambergrise, each five grains; rubbing the oil with the other ingredients powdered; and when the wax is ready to be wrought into sticks, sprinkling in and well stirring the mixture; or by using one ounce of benjamin, one scruple and a half of oil of Rhodium, and five grains of ambergrise, in the same manner. *Lewis's Com. of Arts*, p. 370. *Handmaid to the Arts*, vol. ii. p. 34, &c.

Wax-Candles. See CANDLE.

Weaving

WEAVING, in *Manufactures*, is the art of combining and uniting threads together, to form cloth. Stocking-knitting or weaving is a distinct art from cloth-weaving, the manner of combining the thread, being essentially different in the two. In the stocking fabric, the whole piece consists of one continuous thread, which is formed into a series of loops in successive rows; and the loops of each row are drawn through the loops of a former row. See STOCKING-FRAME.

Woven cloth is always composed of two distinct systems of threads, called the warp and the weft: these traverse the piece of cloth in opposite directions, and are usually at right angles to each other. Those threads, (or, as the weavers call them, yarns,) which run in the direction of the length of the web or piece of cloth, are called the warp, and they extend entirely from one end of the piece to the other. The cross thread, or yarn, runs across the cloth, and is called the woof or weft. This is in fact one continued thread through the whole piece of cloth, being woven alternately over and under each yarn of the warp, which it crosses, until it arrives at the outside one. It then passes round that yarn, and returns back over and under each thread, as before; but in such a manner, that it now goes over those yarns which it passed under before, and *vice versa*; thus firmly knitting or weaving the warp together. The outside yarn of the warp, round which the woof is doubled, is called the selvage, and cannot be unravelled without breaking the weft. The strength of the cloth, in the direction of the length, must depend on the threads of the warp; but its strength in the opposite direction will depend upon the weft; and the strength of these two threads should be always properly proportioned to each other.

The combined arts of spinning and weaving are among the first essentials of civilized society, and we find both to be of very ancient origin. The fabulous story of Penelope's web, and, still more, the frequent allusions to this art in the sacred writings, tend to shew, that the fabrication of cloth from threads, hair, &c. is a very ancient invention.

It has, however, like other useful arts, undergone a vast succession of improvements, both as to the preparation of the materials of which cloth is made, and the apparatus necessary in its construction, as well as in the particular modes of operation by the artist. Weaving, when reduced to its original principle, is nothing more than the interlacing of the weft or cross threads into the parallel threads of the warp, so as to tie them together, and form a web or piece of cloth. This art is doubtless more ancient than that of spinning, and the first cloth was what we now call matting, *i. e.* made by weaving together the shreds of the bark, or fibrous parts of plants, or the stalks, such as rushes and ²straws.

This is still the substitute for cloth amongst most rude and savage nations. When they have advanced a step farther in civilization than the state of hunters, the skins of animals become scarce, and they require some more artificial substance for clothing, and which they can procure in greater quantities. Nevertheless, some people are still ignorant of the art of weaving; for the cloth made in the islands of the South sea appears to be made by cementing or gluing the shreds together, rather than by weaving. From the description given by captain Cook, and other circumnavigators, and from the specimens which have been brought to Europe, their cloth, or rather matting, is in general produced by cohesion of the parts, rather than texture. This assimilates it more to the ideas which we attach to paper, or pasteboard, than to those which we form of cloth.

When it was discovered that the delicate and short fibres, which animals and vegetables afford, could be so firmly united together by twisting, as to form threads of any required length and strength, the weaving art was placed on a permanent foundation. By the process of spinning, which was very simple in the origin, the weaver is furnished with threads far superior to any natural vegetable fibres in lightness, strength, and flexibility; and he has only to combine them together in the most advantageous manner.

The art of weaving cloth has been so extensively applied

in almost every civilized country, and the knowledge of its various branches has been derived from such a variety of sources, that no one person can ever be practically employed in all its branches; and though every part bears a strong analogy to the rest, yet a minute knowledge of each of these parts can only be acquired by experience and reflection. We will endeavour to give the reader as comprehensive an idea of the history and progress of this ancient and invaluable art as the nature of the thing, and the limits to which we are necessarily confined, will permit.

The history of this art is very little known, and its great antiquity necessarily involves the earlier eras of it in the most perfect obscurity.

The art of making linen, which was probably the first species of cloth invented, was communicated by the Egyptians, the inhabitants of Palestine, and other eastern nations, to the Europeans. By slow degrees it found its way into Italy; and it afterwards prevailed in Spain, Gaul, Germany, and Britain. The Belgæ manufactured linen on the continent; and when they afterwards settled in this island, it is probable they continued the practice, and taught it to the people among whom they resided.

When it is considered that the wants of mankind are nearly the same in all countries, it is not improbable that the same arts, however varied in their operations, may have been separately invented in different countries. It is not, however, certain that the art of making cloth is one which the Britons invented for themselves.

It is most probable that the Gauls learned it from the Greeks, and communicated the knowledge of it to the people of Britain. It is very certain that the inhabitants of the southern parts of Britain were well acquainted with the arts of dressing, spinning, and weaving, both flax and wool, when they were invaded by the Romans. Nevertheless, we have the authority of Julius Cæsar, that when he invaded Britain, the art of weaving was totally unknown to the Britons.

Whatever knowledge the Britons might possess of the clothing arts, prior to the invasion, it is very certain that these arts were much improved amongst them after that event. It appears from the *Notitia Imperii*, that there was an imperial manufactory of woollen and linen cloth, for the use of the Roman army then in Britain, established at *Venta Belgarum*, now called Winchester.

Many public acts relative to the woollen manufacture, in the earlier period of English history, evidently prove that the greater part of our wool was, for a very long series of years, exported in a raw state, and manufactured upon the continent.

In bishop Aldhelm's book concerning "Virginity," written about A.D. 680, it is remarked, "that chastity alone forms not a perfect character, but requires to be accompanied and beautified by other virtues." This observation is illustrated by the following simile, borrowed from the art of figure-weaving: "It is not a web of one uniform colour and texture, without any variety of figures, that pleaseth the eye, and appeareth beautiful; but one that is woven by shuttles, filled with threads of purple, and many other colours, flying from side to side, and forming a variety of figures and images, in different compartments, with admirable art."

Perhaps the most curious specimen of this ancient figure-weaving and embroidery, now to be found, is that preserved in the cathedral of Bayeux. It is a piece of linen, about 19 inches in breadth, and 67 yards in length, and contains the history of the Conquest of England by William

of Normandy; beginning with Harold's embassy, A.D. 1065, and ending with his death at the battle of Hastings, A.D. 1066. This curious work is supposed to have been executed by Matilda, wife to William, duke of Normandy, afterwards king of England, and the ladies of her court. Although it is certain that the art of figure-weaving was then known in Britain, it must be owned, that the piece of tapestry just mentioned owes most of its beauty to the exquisite needle-work with which it is adorned.

The silk manufacture was first practised in China, and the cotton in India. Both the woollen and linen were borrowed by the English from the continent of Europe; and for many ages, all the improvements in them in this country were first introduced into this country by foreign artificers, who settled amongst us.

About the close of the eleventh century, the clothing arts had acquired a considerable degree of improvement in this island. About that time, the weavers in all the great towns were formed into guilds or corporations, and had various privileges bestowed upon them by royal charters.

In the reign of Richard I., the woollen manufacture became the subject of legislation; and a law was made, A.D. 1197, for regulating the fabrication and sale of cloth.

The number of weavers, however, was comparatively small, until the policy of the wise and liberal Edward III. encouraged the art, by the most advantageous offers of reward and encouragement to foreign cloth-workers and weavers, who would come and settle in England. In the year 1331, two weavers came from Brabant, and settled at York.

The superior skill and dexterity of these men, who communicated their knowledge to others, soon manifested itself in the improvement and spread of the art of weaving in this island.

Many Flemish weavers were driven from their native country, by the cruel persecutions of the duke d'Alva, in the year 1567. They settled in different parts of England, and introduced or promoted the manufacture of baizes, serges, crapes, and other woollen stuffs.

About the year 1686, nearly 50,000 manufacturers, of various descriptions, took refuge in Britain, in consequence of the revocation of the edict of Nantz, and other acts of religious persecution committed by Louis XIV. These improvements chiefly related to silk-weaving.

The arts of spinning, throwing, and weaving silk, were brought into England about the middle of the 15th century, and were practised by a company of women in London, called silk-women. About A.D. 1480, men began to engage in the silk manufacture, and the art of silk-weaving in England soon arrived at very great perfection. See *SILK*.

The civil dissensions which followed this period, retarded the progress of these arts; but afterwards, when the nation was at rest, the arts of peace, and among others that of weaving, made rapid advances in almost every part of the kingdom.

In the latter part of the last century, the invaluable inventions of sir Richard Arkwright, introduced the very extensive manufacture of cotton, and added a lucrative and elegant branch of traffic to the commerce of Britain. The light and fanciful department of the cotton manufacture has become, in some measure, the staple manufacture of Scotland, whilst the more substantial and durable cotton fabrics have given to England a manufacture inferior, in importance and extent, only to the woollen trade.

At the present day, our superiority in point of quality

is universally acknowledged in the cotton manufacture ; but in those of silk, linen, and woollen, it is still disputed by other countries.

Loom.—Weaving is performed by the aid of a machine called a loom. The common loom for plain cloth is a very simple machine ; but some of the varieties which are used for weaving ornamental and figured cloth are very curious : still there are parts common to all. The principal of these are as follows.

1. The yarn-beam, which is a round wooden roller, on which is wound or rolled the warp, or yarns that are to form the length of the piece of cloth.
2. The cloth-beam is a similar roller, on which the cloth is rolled up when woven. The yarns of the warp are extended in parallel lines, between the yarn-roll and the cloth-roll, so as to form a horizontal plane, or sheet, and are combined together by the cross-threads, or weft.
3. The shuttle, which has a hollow to contain a bobbin or pirn of the weft.
4. The heddles, which are threads with loops or eyes, through which the yarns of the warp pass : the heddles are connected with the treadles, upon which the weaver places his feet, to draw down one set of heddles and raise up another, so as to open and separate the warp into two divisions, and allow a passage, called the shed, for the shuttle between them.
5. The reed, which is a frame containing a row of parallel shreds of reeds or cane, and the yarns of the warp pass between them, as it were between the teeth of a comb.
6. The reed is fixed in a frame, called the lay or lathe, which swings upon centres of motion. The use of the reed and lay is to comb or push the threads of the weft close to each other, and make the cloth close and dense.

The operation of weaving or working the loom for plain cloth consists of three very simple movements, *viz.* 1. Opening the shed in the warp alternately, by pressing the two treadles with his feet in opposite directions. 2. Driving or throwing the shuttle through the shed when opened. This is performed by the right-hand, when the fly-shuttle is used, and by the right and left alternately, in the common operation, wherein the shuttle is thrown from one hand and caught in the other. 3. Pulling forward the lay or batten to strike home the weft, and again pushing it back nearly to the heddles. This is done by the left-hand with the fly-shuttle, or by each hand successively in the old way.

There are several different ways of setting up a loom for weaving plain cloth ; but the principal parts are always made the same. We shall first describe that which is used for weaving plain silks : it is shown in perspective in *Plate II. Weaving.* In this *A* is the yarn-roll or beam, on which the thread to form the warp is regularly wound ; *B*, the cloth-beam, or breast-roll, on which the finished cloth is wound up ; *D E*, the treadles, on which the weaver presses his feet ; *dd, ee*, are the heddles, or harnesses. These are each composed of two small rods *dd* and *ee*, connected together by several threads, forming a system of threads, which is called a heddle ; *ee* is another heddle, behind the former. In the middle of each thread of the heddle is a loop, through which a yarn of the warp is passed, every other yarn going through the loops of the heddle *ee*, and the intermediate yarns passing between the threads of that heddle, and afterwards through the eyes or loops of the other heddle *dd*.

The two heddles, *dd* and *ee*, are connected together by two small cords going over pulleys, suspended from the top of the loom, so that when one heddle is drawn down, the other will be raised up. The heddles receive their

motion from the levers or treadles *D E*, moved by the weaver's feet. The yarns of the warp being passed alternately through the loops of the two heddles, by pressing down one treadle, as *E*, all the yarns belonging to the heddle *ee* are drawn down ; and by means of the cords and pulleys, the other heddle *dd*, with all the yarns belonging to it, are raised up ; leaving a space, called the shed, of about two inches between the yarns, for the passage of the shuttle.

F, G G, H, (*fig. 2.*) is a frame, called the batten or lay, suspended by the bar *F*, from the upper rails of the loom, so that it can swing backwards and forwards, as on a centre of motion ; the bottom bar *H* is much broader than the rails *G G*, and projects before the plane about an inch and a half, forming a shelf, called the shuttle-race. The ends of the shuttle-race *H* have boards nailed on each side, to form two short troughs or boxes *I I*, in which pieces of wood or thick leather *kk*, called peckers or drivers, traverse. The peckers are guided by two small wires, fixed at one end to the uprights *G G*, and at the other to the end-pieces of the troughs *I I*. Each pecker has a string fastened to it, tied to the handle *y*, which the weaver holds in his right-hand when at work, and with which he pulls, or rather snatches, each pecker either to the right or left alternately.

R is the reed : it is a small frame, fixed upon a shuttle-race *H*, containing a number of small pieces of split reeds or canes ; or else of pieces of flat wire, of steel or brass ; but the cane is most common, although the frame is called the reed. When *fig. 2.* is in its place in the loom, the yarns of the warp pass between the canes or dents of the reed. In *fig. 2.* the reed is represented without the top or piece which covers it, and which is called the lay-cap. It is a rail of wood with a longitudinal groove along its lowermost side, for the purpose of sustaining the upper edge of the reed. The lay-cap is that part of the machine on the middle of which the weaver lays hold with his left-hand when in the act of weaving.

The shuttle (*see Plate I.*) is a small piece of wood pointed at each end, from three to six inches long. It has an oblong mortise in it, containing a small bobbin or pirn, on which is wound the yarn which is to form the weft ; and the end of this yarn runs through a small hole in the shuttle, called the eye. The shuttle has two little wheels on the under side, by which it runs easily upon the shuttle-race *H*.

Operation.—The weaver sits on the seat *M*, (*fig. 1.*) which hangs by pivots at its ends, that it may adapt itself to the ease of the weaver when he sits upon it. It is lifted out when the weaver gets into the loom, and he puts it in again after him. He leans lightly against the cloth-roll *B*, and places his feet upon the treadles *D E*. In his right-hand he holds the handle *y* (*fig. 2.*), and by his left he lays hold of the rail, called the lay-cap, which crosses the batten or lay *G G*, and serves to support the upper edge of the reed *R*. He commences the operations by pressing down one of the treadles with his foot : this depresses one-half of the yarns of the warp, and raises the other, as before-described. The shuttle is previously placed in one of the troughs *I*, against the pecker *K*, belonging to that trough. By the handle of the pecker, with a sudden jerk, he drives the pecker against the shuttle, so as to throw it across the warp upon the shuttle-race, into the other trough *I*, leaving the yarn of the weft, which was wound on the bobbin after it, in the space between the divided yarns. With his left-hand he pulls the lay towards him ; and, by means of the reed, the yarn of the weft, which before was lying loose between the warp, is driven up towards

the cloth-roll : the weaver now presses down his other foot, which reverses the operation, pulling down the heddle which was up before, and raising that which before was depressed. By the other pecker he then throws the shuttle back again, leaving the woof after it between the yarns of the warp ; and, by drawing up the batten, beats it close up to the thread before thrown.

In this manner the operation is continued until a few inches are woven ; it is then wound upon the cloth-roll, by putting a short lever into a hole made in the roll, and turning it round, a click acting in the teeth of a serrated wheel, prevents the return of the roll. At each end of the yarn-roll A, (*fig. 1.*) a cord is tied to the frame of the loom ; the other ends of the cords have weights hanging to them. The rope causes a friction, which prevents the roll from turning (unless the yarn is drawn by the cloth-beam), and always preserves a proper degree of tension in the yarn.

T T (*fig. 1.*) are two smooth sticks (cotton-weavers have usually three) put between the yarns, to preserve the lease, and keep the threads or yarns from entangling.

In cotton-weaving these sticks or rods are kept at an uniform distance from the heddles, either by tying them together, or by a small cord with a hook at one end, which lays hold of the front rod, and a weight at the other, which hang over the yarn-beam.

The cloth is kept extended during the operation of weaving, by means of two hard pieces of wood, called a templet, with small sharp points in their ends, which lay hold of the edges, or selvages, of the cloth.

These pieces are connected by a cord passing obliquely through holes, or notches, in each piece. By this cord they can be lengthened or shortened, according to the breadth of the web.

They are kept flat after the cloth is stretched by a small bar turning on a centre fixed in one of the pieces of wood. This stretcher is called the templet. Silk-weavers usually stretch their cloth by means of two small sharp-pointed hooks fastened to the ends of two strings, with little weights at the other ends ; and the strings are made to pass over little pulleys in each side of the loom, at a suitable distance from the selvages of the cloth.

The perfection of the work depends very much upon the previous operations which the yarn must undergo. It is obvious that the yarns of the warp must be stretched with great parallelism and equality of tension, so that when the cloth is finished, every individual yarn may bear an equal share of any strain which tends to tear the cloth ; hence great care must be taken to stretch the yarns of the warp to an equal length, and roll them with great regularity upon the yarn-roll. These operations are called warping and beaming. Previous to warping, the yarn must be prepared by sizing or starching, in order to cement all the loose fibres, and render the yarn smooth.

The spinners of yarn, whether they employ machinery or not, usually reel the yarn into skeins and hanks of a determinate length ; and the weight of these hanks, or the number which will weigh one pound, is the denomination for the fineness of the yarn. (See *Manufacture of COTTON.*) In this state the yarn is bought by the weaver. The hanks of yarn are first boiled in water ; if it is linen-yarn a little soap and potash are put into the water, and for cotton-yarn a small portion of flour is added, to render the thread firm. When the hanks are perfectly dry they are wound off upon bobbins, each thread having a separate bobbin, and a certain length is wound upon each. This winding is performed by a very simple hand-wheel to turn the bobbin rapidly round, the hanks of yarn being extended upon a reel, or

over two small reels placed at a distance asunder, which are called wisks.

Warping.—The object of this operation is to stretch the whole number of parallel threads which are to form the warp of the cloth to an equal length. For this purpose as many of the above bobbins are taken as will furnish the quantity of threads which is required in the warp of the piece of cloth. The bobbins are usually one-fourth or one-sixth of the number of threads required, and are mounted on spindles in a frame, so that the thread can draw off freely from them. All these threads are drawn off at once, so as to combine them all into one clue, which will be ready for the warp. The ancient method was to draw out the warp at full length, and stretch it in a field ; and this is still practised in India and China, but is so very uncertain in our climate that it is seldom used. The present mode of warping is either by the warping-frame or warping-mill.

The warping-frame is a large wooden frame, which is fixed up against a wall in a vertical position. The upright sides of the frame are pierced with holes to receive wooden pins, which project sufficiently to wind the clue of yarns for the warp round them.

The operator having the threads which are to compose the warp wound on the bobbins before-mentioned, places those bobbins in a frame ; then tying the ends of all the threads together, and attaching them to one of the pins at one end of the frame, he gathered all the threads in his hand into one clue ; and permitting them to slip through his fingers, he walked to the other end, where he passed the yarns over the pin fixed there, and then returned to the former end of the frame and passed the warp over another pin, then went back again, and so on till he formed the required length of the warp. This being done, he secured the end of the warp by crossing it round the pin, and then he worked back and returned over all the same space again, laying the threads over the same pins, so as to double the clue ; and he repeated the doubling until the number of threads necessary for the breadth was made up. The number of doublings would be according to the number of bobbins and threads which he took in his hand at once.

This method is used very much in France, particularly at Lyons : it is also used in Devonshire. It is adapted to the weaving carried on in cottages, because the frame is fixed close to the wall, and takes little or no room ; but the warping-mill or reel is very superior, and is adopted in all improved manufactures where the warping is a separate business, and is usually done at the mill where the yarn is spun.

The warping-mill is a large reel of a cylindrical form, or rather of a prismatic form, being made with twelve, eighteen, or more sides. The reel is usually about six feet diameter and seven feet high : it is turned round on a vertical axis by a band, passing from a grooved wheel which is turned by a winch, and is placed beneath the seat on which the warper sits. (See a figure of the warping-machine for silk *Plate Silk, fig. 6.*) The bobbins which contain the yarn are placed on a vertical rack suspended from the ceiling, and the threads from them are all collected together and passed between two small upright rollers in a clue, which is wound up by the reel when it is turned round. To guide the clue and distribute it equally on the length of the reel, the above rollers are fixed on a piece of wood, which slides perpendicularly on an upright bar fixed at one side of the reel. The sliding-piece is suspended by a small cord, wrapped round a part of the perpendicular axis that rises above the reel. The cord passes over a pulley at the top of the upright bar, and goes down to the sliding-piece which carries the two rollers. When the reel turns round, the guide-rollers are slowly

drawn up by the coiling of this cord round the axis; and the yarn is wound in a regular spiral about the reel, until the length which the warp requires is wound upon it. When the full length of the yarn is wound on the reel, the clue of thread is crossed over pins projecting from the frame of the reel, and the mill is then turned the reverse way, so that the slider and guide-rollers descend, and the yarn is laid downwards along the same spiral which it before ascended, so as to double the clue of thread; and this doubling is repeated until the required number of threads is collected together in one clue upon the reel.

When the warp is thus completed, it is taken off the reel and wound upon a stick into a ball; the crossings which distinguish the different returns or doublings of the simple clue being first properly secured, as a means of dividing the warp into as many equal portions as is necessary for the convenience of the weaver, in counting the threads in the succeeding operation of beaming.

There is likewise another kind of division of the threads of the warp; this is called the leaf, and serves to separate all the threads which are to go through one of the heddles of the loom, from those which are to go through the other heddle. To effect this separation, the bobbins from which the threads are drawn are arranged in two rows, and a thread is alternately drawn from the upper row and from the lower row. Then at the beginning and end of every doubling of the warp, the threads of one row of bobbins are crossed over the threads of the other row, and two pins are put into the crossings to retain them. These pins are put into holes made in pieces of board fixed to the warping-reel. One of these boards at the top of the reel is fixed fast, but the other is moveable, and can be fixed at any part of the reel, according to the length of the warp.

In the most improved warping-machines, the separation is made by an apparatus called in Scotland the heck. It consists of a row of steel pins with eyes through one end of each for the threads to pass through like large needles. These are stuck into two pieces of wood, by which they are supported in a row near to the warping-reel. Every alternate pin in the row is fastened in one piece of wood, and the intermediate pins are fastened in the other piece, so that by lifting up one piece of wood the pins and threads belonging to it will be raised up, whilst the intermediate pins and threads are held down. This occasions the division of the threads, and a pin is put in to keep them so divided. The other piece of wood is then lifted up, which occasions all the threads to be crossed; that is, every thread forms a cross over that which is adjacent to it. A second pin is then put in, and before the warp is taken off from the reel, this crossing is secured by a string.

Beaming.—When the weaver receives his warp in a large ball or bundle, he proceeds to roll it up regularly upon the yarn-roller of his loom: this is called beaming. For this purpose he employs an instrument called a separator, or ravel, which consists of a number of shreds of cane, fastened together, and fixed to a rail of wood, like the teeth of a long comb; the threads are intended to be put into the spaces between these teeth, so as to stretch the warp to its proper breadth.

Ravels are somewhat like reeds, but much coarser, and are also of different dimensions. One proper for the purpose being found, one of the small divisions of the warp is placed in every interval between two of the teeth. The upper part of the ravel, called the cape, is then put on, to secure the threads from getting out between the teeth, and the operation of winding the warp upon the beam commences. In broad works, two persons are employed to

hold the ravel, which serves to guide the threads of the warp, and to spread them regularly upon the beam; one or two other persons keep the threads at a proper degree of tension, and one more turns the beam upon its centre.

The knottings which secure the crossings or doublings made in warping, are very useful to the weaver in beaming, to ascertain the number of threads, and to distribute them with regularity. He cuts the knotting before he can put the warp in the ravel, but he still keeps them distinct by a small cord.

The French weavers use a small reel, upon which they wind the warp from the ball, and then from this reel they draw off the warp through the ravel, by winding up the beam. The reel is loaded with a weight, to make a regular friction, and draw the warp with a regular tension.

Drawing.—The warp being regularly wound upon the beam, the weaver must pass every yarn through its appropriate eye or loop in the heddles; this operation is called drawing. Two rods are first inserted into the leaf formed by the pins in the warping-mill, and the ends of these rods are tied together; the twine by which the leaf was secured is then cut away, and the warp stretched to its proper breadth. The yarn-beam is suspended by cords behind the heddles, somewhat higher, so that the warp hangs down perpendicularly. The weaver places himself in front of the heddles, and opens the eye of each heddle in succession; and it is the business of another person, placed behind, to select every thread in its order, and deliver it to be drawn through the open eyes of the heddles. The succession in which the threads are to be delivered is easily ascertained by the leaf-rods, as every thread crosses that next to it. The warp, after passing through the heddles, is drawn through the reed by an instrument called a sley, or reed-hook, and two threads are taken through every interval in the reed.

The leaf-rods being passed through the intervals which form the leaf, every thread will be found to pass over the first rod, and under the second; the next thread passes under the first, and over the second, and so on alternately. By this contrivance every thread is kept distinct from that on either side of it, and if broken, its true situation in the warp may be easily and quickly found. This is of such importance, that too much care cannot be taken to preserve the accuracy of the leaf. There is likewise a third rod, which divides the warp into what is usually called *splits*, for two threads alternately pass over and under it; and these two threads also pass through the same interval betwixt the splits of the reed.

These operations being finished, the cords or mounting which move the heddles are applied; the reed is placed in the lay, or batten, and the warp is knotted together into small portions, which are tied to a shaft, and connected by cords to the cloth-beam, and the yarns are stretched ready to begin the weaving.

Manner of Weaving.—The operations of weaving are simple, and soon learned, but require much practice to perform them with dexterity.

In pressing down the treadles of a loom, most beginners are apt to apply the weight or force of the foot much too suddenly. The bad consequences of this are particularly felt in weaving fine or weak cotton-yarn; for the body of the warp must sustain a stress nearly equal to the force with which the weaver's foot is applied to the treadle. The art of spinning has not yet been brought to such perfection as to make every thread capable of bearing its fair proportion of this stress. Besides this, every individual thread is subjected to all the friction occasioned by the heddles and splits of the reed, between which the threads pass, and with

which they are generally in contraft when rifing and finking. A fudden preffure of the foot on the treadle muft caufe a proportional increafe of the ftreffs upon the warp, and alfo of the friction. As it is impoffible to make every thread equally ftrong and equally tight, thofe which are the weakeft, or the tighteft, muft bear much more than their equal proportion of the ftreffs, and are broken very frequently. Even with the greateft attention, more time is loft in tying and replacing them, than would have been fufficient for weaving a very confiderable quantity into cloth.

If the weaver, from inattention, continues the operation after one or more warp-threads are broken, the confequence is ftill worfe. The broken thread cannot retain its parallel fituation to the reft, but croffing over or between thofe neareft to it, either breaks them alfo, or interrupts the paffage of the fhuttle: it frequently does both.

In every kind of weaving, and efpecially in thin wiry fabrics, much of the beauty of the cloths depends upon the weft being well ftretched. If the motion given to the fhuttle be too rapid, it is very apt to recoil, and thus to flacken the thread. It has alfo a greater tendency, either to break the woof altogether, or to unwind it from the pirn or bobbin of the fhuttle in doubles, which, if not picked out, would deftroy the regularity of the fabric. The weft of mufins and thin cotton goods is generally woven into the cloth in a wet ftate.

This tends to lay the ends of the fibres of cotton fmooth and parallel, and its effect is fimilar to that of dreffing of the warp.

The perfon who winds the weft upon the pirn ought to be very careful that it be well formed, fo as to unwind freely. The beft fhape for thofe ufed in the fly-fhuttle is that of a cone; and the thread ought to traverfe freely round the cone, in the form of a fpiral, or fcrew, during the operation of winding.

The fame wheel which is ufed for winding the warp upon the bobbins preparatory to warping, is alfo fit for winding the weft on the pirn. It only requires a fpindle of a different fhape, with a fcrew at one end, upon which the pirn, or bobbin of the fhuttle, can be fixed. The wheel is fo conftructed, that the fpindles may be eafily fhifted, to adapt it for either purpofe.

The reeds are formed of a number of fhort pieces of reed or cane, or of brafs wire, faftened parallel to each other between two fticks, and cemented with pitch. This frame is enclosed between two pieces of the frame of the lay, one of which is made wide, to form the fhuttle-race; the other piece, which is the lay-cap, extends acrofs the frame, but is fitted fo that it can be eafily removed to take away the reeds, and fubftitute a finer or coarfer fort, as the nature of the goods to be woven require. The manufacture of reeds, both of cane and of fteel, is a feparate trade. Thefe are fully defcribed in *Les Arts et Metiers*, vols. 9 and 15.

To render the fabric of the cloth uniform in thicknefs, the lay or batten muft be brought forward with the fame force every time.

In weaving fome kinds of foft or light goods, the reed is not fixed faft to the lay-cap, but is held in its place by a long thin piece of wood, which is elastic, and yields or fprings when the weft is beaten up. In fome cafes the reed is fupported by a double woollen cord, ftretched acrofs the lay, juft beneath the lay-cap, and twifted; this bears the reed, and is very elastic, but can be rendered more ftiff by twifting the two cords tighter.

In the common operation of weaving, a regular force of the ftroke for beating up the weft muft be acquired by practice. It is, however, of confequence to the weaver to

mount or prepare his loom in fuch a manner, that the range or fwing of the lay may be in proportion to the thicknefs of his cloth. As the lay fwings backwards and forwards, upon centres placed above, its motion is fimilar to that of a pendulum. Now the greater the arc, or range through which the lay paffes, the greater will be its effect in driving home the weft ftrongly, and the thicker the fabric of cloth will be, as far as that depends upon the clofenefs of the weft. For this reafon, in weaving coarfe and heavy goods, the heddles ought to be hung at a greater diftance from the place where the weft is ftuck up, and confequently where the cloth begins to be formed, than would be proper in light work. The line of the laft wrought fhut of weft is called by the weavers the fell. The pivots upon which the lay vibrates ought, in general, to be fo placed, that the reed will be exactly in the middle, between the fell and the heddles, when the lay hangs perpendicularly. As the fell is constantly varying in its fituation during the operation, it will be proper to take its medium; that is, the place where the fell will be when half as much is woven as can be done without taking it up on the cloth-roll, and drawing frefh yarn from the yarn-roll.

The periods for taking up the cloth ought always to be fhort in weaving light goods; for the lefs that the extremes of the fell vary from the medium, the more regular will be the arc or fwing of the lay. Mr. James Hall had a patent, in 1803, for a method of perpetually winding up the cloth-beam, fo as to take away the cloth as faft as it was woven, or fhut by fhut. This was effected in a fimple manner by a ratchet-wheel fixed on the end of the cloth-beam, and a proper catch to move it round one tooth at a time: the catch was actuated by the motion of the lay. A fimilar method is ufed in ribband-weaving.

The variations in the ftructure of looms from that which we have defcribed, are not material. The framing is varied in almoft every different kind of loom, and ought always to be fuitable in ftrength to the kind of cloth which is to be woven. The loom ufed for filk is very flight in all its parts; but for carpet and fail-cloth it muft be very ftiong.

In looms for heavy goods, the cloth-beam is not placed at the breaft of the weaver, as it is fo large that it would impede his working; the cloth is therefore paffed over a fixed bar in the place of the cloth-beam reprefented, and the beam is placed lower down, and near the weaver's feet, out of the way of his knees. The heddles are connected by levers, in fome looms, inftead of pulleys; but the effect is always the fame; *viz.* to make one heddle afcend when the other defcends. For weaving fine goods, the heddles would be inconveniently clofe together, if all the yarns went through two heddles; hence they ufe four heddles inftead of two; but their action is juft the fame, becaufe they are connected together in pairs, and when one pair rifcs the other pair finks. Many looms are ftill made without the fly-fhuttle; and in that cafe the fhuttle is merely thrown from one hand to the other, and then thrown back again: this obliges the weaver to change his hands continually, and the operation is more complicated. For wide cloths, which are more than a man can reach acrofs, two perfons were always employed before the fly-fhuttle was introduced, which is only within a few years; but by its affiftance one perfon can weave the greateft breadths. The fly-fhuttle is the beft for all kinds of work, and its conftruction is fo fimple that no other ought to be ufed.

Treatment of different Kinds of Yarns.—The manner of weaving all kinds of plain cloth is much the fame, whether it is wool, filk, flax, or cotton; except that the two latter

require what is called *dress*ing. Silk and woollen warps require little preparation after being put into the loom, except to clear the yarn occasionally with a comb, to remove knots or lumps which might catch in passing through the reed; the comb detects such lumps, and they are removed with the assistance of a pair of scissors. Flax and cotton, but particularly the latter, require the warp to be dressed with some glutinous matter, to cement the fibres, and lay them close. This is applied in a fluid state, and as the weaving does not proceed well after it is suffered to dry, the warp is dressed with a brush when in the loom, a small quantity at a time, immediately before it is woven.

Dressing.—The use of dressing is to give to yarn sufficient strength or tenacity, to enable it to bear the operation of weaving into cloth. By laying smooth all the ends of the fibres of the raw materials, from which the yarn is spun, it tends both to diminish the friction during the process, and to render the cloth smooth and glossy when finished. The dressing in common use is simply a mucilage of vegetable matter boiled to a consistency in water. Wheat-flour, boiled to a paste like that used by book-binders, or sometimes potatoes, are commonly employed. These answer sufficiently well in giving to the yarn both the smoothness and tenacity required; but the great objection to them is, that they are too easily affected by the action of the atmosphere. When dressed yarn is allowed to stand exposed to the air for any considerable time, before being woven into cloth, it becomes hard, brittle, and comparatively inflexible. It is then tedious and troublesome to weave, and the cloth is rough, wiry, and uneven. This is chiefly remarked in dry weather, when the weavers of fine cloth find it necessary to work up their yarn as speedily as possible, after it is dressed. To counteract this inconvenience, herring or beef brine, and other saline substances which attract moisture, are sometimes mixed in small quantities with the dressing: but this has not been completely and generally successful; probably, because the proportions have not been sufficiently attended to; for a superabundance of moisture is equally prejudicial with a deficiency. The variations of the moisture of the air are so great and frequent, that it is impossible to fix any universal rule for the quantity of salt to be mixed. Some weavers put butter-milk in the paste.

To apply the dressing, the weaver must suspend the operation of weaving, whenever he has worked up that quantity of warp which he has dressed, or within two or three inches; he then quits his seat, and applies the comb to clear away knots and burs; next pushes back the lease-rods towards the yarn-roll, one at a time, and if they slide freely between the yarns, it shews they are clear from knots; he then brushes the yarn with the paste by two brushes, holding one in each hand. The superfluous humidity is afterwards dried by fanning the yarns with a large fan, and then a small quantity of grease is brushed over the yarn; the lease-rods are returned to their proper position, and the weaving is resumed.

Dressing is of the first importance in weaving warps spun from flax or cotton; for it is impossible to produce work of a good quality, unless care be used in dressing the warp.

The same practice, when used upon silk, has a very destructive tendency: it injures the colours of the silk when used, as it is sometimes very improperly, by the weavers of white satin. The injury done to the work is irreparable. In cotton, the operation of dressing is indispensable; but in silk, this is by no means the case.

The preparation of paste or size for warp, has been the subject of several patents. Mr. Foden, in 1799, recom-

mends a quantity of calcined gypsum, or plaster of Paris, to be reduced to a very fine powder, and then mixed with alum, sugar, and the farina or starch of potatoes, or any other vegetable farina. This powder, when mixed well with cold water, forms a soft paste, to which boiling water is to be added, and the mixture thoroughly stirred till it becomes sufficiently gelatinous for use.

Another size, for which Mr. Wilks had a patent in 1801, is prepared as follows:—The starch or flour is to be extracted from any kind of potatoes which are mealy when boiled, by grating them while raw (but washed clean) into a tub of water. The water, thus impregnated with the grated potatoes, is run through a sieve or strainer, which will retain the coarser and fibrous parts of the potatoes, but admit the finer particles, constituting the starch or flour, to pass with the water into a vessel beneath the sieve or strainer. This water must remain in the vessel several hours undisturbed, to permit the starch to subside to the bottom; then the water is poured off, and the starch so obtained is put into fresh water, and passed through a finer sieve into another tub, where the starch is left to subside to the bottom as before, and the water is again poured off.

About two-thirds the quantity of potatoes, which furnished the starch, are also to be boiled without peeling, so as to make them mealy when boiled; they are then mashed, and diluted with water, so that they will pass through a sieve into a boiler. In this the mashed potatoes are heated till they almost boil; and the starch from the grated potatoes is then to be added, and the whole boiled and stirred for 20 minutes, when it will become paste proper for use. It should be spread in a flat open vessel to cool.

Improved System of Weaving by Machinery.—In our article COTTON we mentioned that weaving-ooms, worked by mechanical power, were then coming into use: since the time that article was printed these have made great advances; but to use them with advantage, the preparatory processes of warping and dressing must be conducted in a particular manner. Many attempts have been made to diminish the number of operations through which the yarn must pass by combining several together. Mr. Stuart had a patent in 1800 for sizing or starching cotton-yarn whilst in the cop, so that it would be ready to warp at once. Mr. Marland had a patent in 1805 for the same object: his plan was to expose the cops of cotton to the action of the hot starch in an exhausted receiver; the pressure of the atmosphere being thus removed, the size penetrated readily to the centre. It was found difficult to dry the cop perfectly, and the threads were sometimes so glued together as to render the winding off difficult.

Another plan has therefore been introduced both for flax and cotton: this is to wind off the yarn from the cop or bobbin in which it is spun, and gather it upon the bobbins ready for the warping; by this manner the reeling is saved. A small quantity of starch is applied to the yarn during the operation, by causing it to pass over a horizontal wooden cylinder, which revolves on its axis in a trough filled with fluid starch. The threads, in passing from the cop to the bobbin, are drawn over the upper surface of the cylinder, and receive the starch with which it is covered. The winding machine for this actuated a great number of bobbins at once; the warping is then conducted, as we have before described, and the dressing is performed in the loom whilst weaving, that is, if woven by hand; but for the power-loom it is dressed previously to placing it in the loom.

Dressing Machines.—Mr. Johnson, of Stockport, had a patent, in 1804, for a method of dressing whole webs of warp at

once, by a machine. The yarns were wound off from the bobbins or cops of the spinning machines upon beams or rollers. Several of these rollers were placed parallel to each other, in an horizontal direction, at the opposite ends of the machine, from three to six at each end; and the yarns from them were all combined together in one web, which was received and rolled up on the yarn-beam of the loom placed in the middle of the machine, and raised up considerably above the other rollers, so that the yarns proceeded from both ends of the machine towards the middle. In their passage they passed through several reeds to keep them separate, and were supplied with the paste by passing over two cylinders revolving in a trough of fluid paste. This paste was dressed or worked into the yarn by means of two brushes, of a length equal to the breadth of the web; one of the brushes acted upon the upper side of the yarns, and the other on the lower side. A similar pair of brushes were applied at both ends; each brush had a motion given to it by means of cranks, exactly similar to the movement with which the weaver brushes the yarn in the loom. Near the yarn-roller a fan was placed, like that used in a winnowing machine, which blew a current of air through the yarns of the warp to dry them before they were rolled up by the beam. To preserve the lease, the yarns were conducted through a pair of heddles, similar to those of the loom, but they remained slack to avoid friction. The machine was moved by the mill with a constant and regular movement.

When a warp is thus warped, beamed, and dressed, the yarn-beam is carried to a loom, on which the yarn is just exhausted, and is made to replace the empty yarn-roll. The ends of the yarn are joined to the old yarns by twisting, and are thus drawn through the heddles and reed, so that the weaving can be resumed with very little loss of time, and the weaver can proceed with his work without any interruption for dressing. The principal objection to the above machine is the friction which the yarns must undergo in brushing, and in passing through so many reeds: it was, however, practised in a large work at Stockport; but the weaving was performed by hand.

Another dressing machine was invented by Mr. McAdam, and he obtained a patent in 1806: it is practised by Mr. Monteith, at Pollockshaws near Glasgow. This machine is very much like the former in its manner of action. Instead of using three, four, or six beams at each end of the machine, there are only two beams, each containing one half the number of yarns for the intended warp. The starch is supplied in the same manner as the former, or sometimes by making the two yarn-beams themselves turn in a trough of starch without employing a separate cylinder. The brushing is performed in a more simple and effectual manner by using cylindrical brushes, which revolve with a regular motion, two of them are applied on the upper side of the warp, and two on the lower side; also four fanners are applied to dry the warp instead of one. The yarns were conducted between reeds and through heddles, like the first machine; and hence the same objection of friction applies to both.

Mr. Duncan, in his *Essays on Weaving*, describes another method of dressing warps, which is practised by Mr. Dunlop at Barrowfield. In this the yarn is warped and beamed in the usual manner, upon a yarn-roll: from this the yarn is unwound, and taken up upon another beam; and in its passage from one to the other it is extended, so that the picking and clearing can be performed in the usual way by hand with a comb and scissors, and the dressing is applied with brushes in the usual way: beneath the warp a fan is placed, to blow a current of air up through the yarns and dry them. In this machine all the operations, except the fanning, are

performed by hand; the advantage, therefore, consists only in the division of labour, by making the dressing and weaving distinct operations.

Power-Looms.—In the article COTTON we have mentioned Mr. Dolignon's claim to the invention of weaving by mechanical power.

The original project, we believe, was by M. De Gennes, and is published in the *Philosophical Transactions* for 1768, N^o 140. See also Lowthorp's *Abridgment*, vol. i. p. 499. This is a very ingenious invention. The fly-shuttle was not then invented, and he supplied the want of it by a contrivance which held the shuttle as it were in a hand by fingers; this carried it half way through the cloth, and then it was transferred to another similar hand, which drew it through the remainder. By this means there was a greater certainty than in throwing the shuttle from one side to the other, because the shuttle always continued engaged with the mechanism: the whole machine is ingenious and worthy of notice.

M. Vaucanson, the celebrated French mechanist, made a machine for weaving ten ribbands at a time, which was worked by a circular motion given by the workman; and it might, therefore, have been worked by mechanical power. This is described in the *Encyclopédie Methodique* in great detail, with ten folding plates, and is an ingenious machine.

We believe both these inventions were prior to that of Mr. Dolignon; and also that the merit of inventing the machine, and first reducing it to practice, is due to Mr. Austin, of Glasgow. In this gentleman's memoir to the Society of Arts, he states, that his first attempt was made in the year 1789, when he entered a caveat for a patent, but did not apply for it further; since that time he made many improvements upon the original plan. In 1796 a report in its favour was made by the Chamber of Commerce and Manufactures at Glasgow; and in 1798, a loom was set at work at Mr. J. Monteith's spinning works, at Pollockshaws near Glasgow, which answered the purpose so well, that a building was erected by Mr. Monteith for containing thirty looms, and afterwards another to hold about two hundred.

Mr. Austin's Power-Loom.—The model from which our drawing (*Plate I. Weaving*) was made, is deposited in the Society of Arts: it is an improvement upon the looms constructed for Mr. Monteith.

The drawing *Plate I.* is a perspective view, exhibiting the whole loom at one glance: it is viewed from the back rather than from the front.

A is a square iron axis extending through the whole length of the machine; to this the power of the first mover is applied by a cog-wheel B, of thirty-six teeth, turned by a pinion of twelve leaves fixed to the axis of the fly-wheel D. A handle is fixed to one of the arms of the wheel to give motion to the model; but in the large machine a live and dead pulley are adapted to the axis of the fly-wheel; and by means of an endless strap, the power is communicated from any convenient part of the mill in which a great number of looms are placed together.

The axis A has several eccentric wheels or camms fixed upon it; as these revolve they give motion to a number of levers or treadles, by which all the usual operations of the loom are performed at the proper intervals: these are,

First, To separate the two parts of the yarns of the warp, as shewn at G, and admit of the passage of the shuttle.

Secondly, To throw the shuttle, in order to lay the weft or cross-threads of the cloth.

Thirdly, To move the lay 7.8, and return it; so that the reed g will beat up the weft close to the fell, or pre-

ceding shoot of the weft : this renders the cloth of uniform texture.

Fourthly, To wind up the cloth upon the cloth-roll, as fast as it is formed by the preceding operations.

The yarns, which are to form the warp of the cloth, are warped in the manner before described upon the yarn-roll F ; and from thence they are extended horizontally to the cloth-roll E, of which only a small part can be seen at the opposite side of the loom : in their way the yarns pass through the eyes of the heddles G H, which effect the first operation above-mentioned. Each heddle is composed of a number of perpendicular threads equal to half the number of yarns in the warp ; these are stretched between two small rods *aa* and *bb*, and in the middle of each thread is a small eye, through which a yarn of the warp is passed ; thus, the first yarn of the warp is passed through the eye of the heddle G, but has no connection with the heddle H, because it passes between its threads. The second yarn is put through the eye of the heddle H, but has no connection with G ; the third yarn is attached to H ; the fourth to G, and so on alternately throughout the whole number. By this means if one heddle is raised up, and the other at the same time depressed, a separation of the yarns will take place as shewn at G, every other yarn being raised up, whilst the intermediate ones are drawn down, so as to admit the passage of the shuttle and weft between them.

The two heddles are moved by camms upon the main axis A ; and they are so connected by short levers I I, which are suspended from the upper part of the loom, that when one heddle is pulled down, the other will be drawn up at the same time, because they are suspended from the opposite ends of the levers I.

The camms on the main axis for the heddles are marked L ; the two are exactly similar, but are reversed upon the axis ; that is, the shortest radius of one is placed on the same side with the longest of the other. They act upon two levers, which are the same as the treadles in a common loom ; only one of these treadles or levers (*viz.* that which belongs to the camm L) can be seen at M, the other lever being concealed from the view ; both levers move on centres at *n* between the small uprights *dd* ; the other ends slide freely up and down between similar uprights at the opposite side of the frame, which cannot be seen in the figure ; the levers are connected with the heddles, which being suspended from the levers I as before mentioned, the levers will therefore move in contrary directions, the one rising when the other is pressed down by the action of the camm on the axis A.

The connection between the levers or treadles M and the heddles G H, is made by cords communicating with two counter-levers O P, which are centered in uprights supported by the frame at the ends of the machine. The counter-levers O P are connected with rods *b* and *k*, and these by a double cord are attached to the heddle-rods *aa* and *bb*.

This machinery which we have now described effects the separation of the warp thus : when the axis A turns round, every revolution of its camms L will cause two separations of the warp, and each one in a different manner, for those yarns which are raised up at one time are drawn down the next.

The second operation, *viz.* throwing the shuttle, is performed by two camms R S, which are reversed to each other upon the axis A. They act upon two levers, only one of which can be seen at T ; they are placed beneath the camms. The shuttle requires to be projected with a sudden jerk ; these levers are therefore centered at *d* on the

same pin as the levers M and N, but the other ends press down smaller levers W, which are centered at the opposite end of the frame, and lie beneath the long levers. The extreme ends of these smaller levers are connected by a strap *f* with a segment of a wheel, which has a long stem of whalebone Y fastened to it ; and by means of two strings, one of which is shewn at *g* 4, it moves the peckers or drivers *z* upon the wires 3, 3, and throws the shuttle. The shuttle, which is shewn in a separate figure, is pointed at each end, and shod with iron : it contains two small rollers 31 31 upon which it runs ; and as they project through both surfaces, it will run either way upwards, or either end first. In the centre of the shuttle is an oblong mortise, containing the pin or bobbin 33, on which the thread for the weft of the cloth is wound ; and the end of the weft marked 34, is brought through a small glass tube, called the eye of the shuttle.

The action of the mechanism for throwing the shuttle is as follows :—By the revolution of the camm R, the long lever beneath it is depressed, and at the same time the extremity of the shorter lever W descends, but with an increased velocity ; this by means of the strap *f* turns the segment of a wheel on its centre, and its tail Y catches the string *g* 4 of the pecker *z*, and makes it strike against the shuttle with such a velocity, as to drive the shuttle out of the trough Q, across the shuttle-race, into the opposite trough, where it will push back the pecker, and remain at rest in the trough ready for the next stroke : by this stroke it will be returned back again with an action similar to the last, but occasioned by the other camm S, and its corresponding levers.

The threads of the warp, which are lowest when the separation takes place, are drawn down by their heddle G or H, so as to lie close upon the shuttle-race, and cause no obstruction to the passage of the shuttle. To facilitate this, the shuttle must be very smooth on the surface, that it may not catch the threads and be stopped. The shuttle-race is inclined towards the reed, both that the yarn may lie flat upon it, and that the shuttle may not be liable to run off its race ; for as it leaves the weft, which is drawn off from its bobbin, in the space between the divided yarns of the warp, it might be drawn off its race sideways, without this precaution. In this manner the second operation is performed.

The third motion is that of the reed *g* : this is fixed close behind the shuttle-race, and is a frame containing a great number of parallel slips of reed or cane ; between these the yarns of the warp pass, and when the whole frame of reeds is moved towards the cloth-roll E, they will act in the manner of a comb, to beat up the thread of the weft, which is left by the shuttle lying loosely between the yarns of the warp.

For this purpose, the shuttle-race, reeds, peckers, &c. and their stem Y, with its segment of a wheel, are all placed on a frame which moves on hinges at the lower ends, 8, of the two upright sides 7 8. This frame, which is termed the lay, is drawn backwards by means of straps 10, 10, rolled upon pulleys 11, fastened upon the axis 12 ; upon this same axis are two other smaller pulleys, upon which two straps, 13, are rolled, to connect with the long levers 14, which are moved by the camms 15, upon the axis A.

The long levers, 14, are centered at one end of the frame, and the pulleys on the axis, 12, being of different diameters, the motion of the reeds will be performed very quickly. To move the lay in a contrary direction, and give the stroke to beat up the weft, two large weights, like *m*, are suspended by straps from pulleys on an horizontal axis, which carries two larger wheels *x* ; on these, straps are wound, to commu-

licate with the upright sides, 7 8, of the lay, and draw it forwards.

When the loom is acting very quickly, these weights would not act with sufficient sharpness to throw the reeds against the threads of the weft with the proper force.

The weights are therefore connected by spiral wire-springs, with long levers 16, which are pressed down by a camm or rather tappet 17, fixed on the main axis. These levers act before the lay is at liberty to move, and by pressing down the levers extend the springs; consequently, as soon as the camm 15 suffers the lever 14 to rise, the springs act instantaneously, to throw the lay and the reeds forwards to beat up the weft.

The instant after the blow has been given, the lay is drawn back again by the camm 15, and returned into the vertical position, in which situation the lay must continue whilst the shuttle is thrown; for this purpose, the out-sides of the camms 15 are portions of circles. This completes the third motion.

As fast as the cloth is fabricated by the foregoing movements, it is gathered upon the cloth-roll E. This is turned slowly round by a small crank 19, on the extreme end of the main axis A; the crank moves a small rod 20 up and down, in order to turn a small ratchet-wheel round one tooth each revolution of the main axis; the return of the ratchet is prevented by a click. On the axis 21 of the ratchet-wheel is an endless screw, to engage the teeth of a cog-wheel upon the end of the cloth-roll, and give it a slow motion.

The yarn is kept to a proper degree of tension by the friction occasioned by a line 28 passed twice round the yarn-roll, one end being fastened to the frame, and the other to a lever 30, loaded with a weight.

The framing of the loom is too evident to need description. In the construction of the machine, the principal circumstance to be attended to, is the figure of the different camms; also that they are placed upon the axis A in the proper positions relative to each other. These cautions will ensure the accurate performance of the machine.

The camm R or S, for throwing the shuttle, is formed with a sudden beak or projection, that it may strike the levers T down instantaneously, and throw the shuttle; from this beak the curve continues circular for some distance, that the lever may be held stationary; the remainder of the camm gradually diminishes its radius like a spiral, and quits the lever, in order to leave it at liberty to rise up when its corresponding lever is forced down by the beak of the other similar camm S.

The camm L for the heddles is made circular where it is to come in contact with the lever, and which is all the time it is in action. This occasions the levers and heddles to be stationary whilst the shuttle is thrown.

The inventor states that, by the addition of some simple improvements, his looms have the following advantages; viz. 300 or 400 of them may be worked by one water-wheel, or steam-engine, all of which will weave cloth in a superior manner to what can be done in the common way. They will go at the rate of 60 shoots in a minute, making two yards height of what is called a nine hundred web in an hour. They will keep regular time in working, stop and begin again, as quick as a stop-watch. They will keep constantly going, except at the time of shifting two shuttles, when the weft on the pirns is exhausted. In general, no knots need be tied, and never more than one in place of two, which are requisite in the common way when a thread breaks. In case the shuttle stops in the shed, the lay will not come forwards, and the loom will instantly stop work-

ing. They will weave proportionally slower or quicker, according to the breadth and quality of the web, which may be the broadest now made. They may be mounted with a harness or spot-heddles, to weave any pattern, twilled, striped, &c.

There is but one close shed, the same in both breadths, and the strain of the working has no effect on the yarn behind the rods.

The fell and temples always keep the same proper distance. There is no time lost in looming, or cutting out the cloth; but it is done while the loom is working, after the first time.

The weft is well stretched, and exactly even to the fabric required.

Every piece of cloth is measured to a frow's breadth, and marked where to be cut at any given length.

The loom will work backwards in case of any accident, or of one or more shoots missing. Every thread is as regular on the yarn-beam as in the cloth, having no more than two threads in the runner. If a thread should appear too coarse or fine in the web, it can be changed, or any stripe altered at pleasure. They will weave the finest yarn more tenderly and regularly than any weaver can do with his hands and feet.

When a thread, either of warp or weft, breaks in it, the loom will instantly stop, without stopping any other loom, and will give warning by the ringing of a bell. A loom of this kind occupies only the same space as a common loom; the expence of it will be about half more; but this additional expence is more than compensated by the various additional machinery employed for preparing the yarn for the common loom, and which this loom renders entirely unnecessary.

The preparatory processes of reeling, winding, warping, beaming, and looming, and the interruptions occasioned by combing, dressing, fanning, greasing, drawing bores, shifting heddles, rods, and temples, which is nearly one-half of the weaver's work, do not happen in these looms. The general waste accompanying the above operations is stated at about six per cent. of the value of the yarn, all which occur in the operations of the common loom. The power-loom, without further trouble, performs every operation after the spinning, till the making of the cloth is accomplished, by which a saving is effected of about 20 per cent. of the yarn.

The heddles, reed, and brushes, will wear longer than usual, from the regularity of their motion. More than one-half of workmanship will be saved; one weaver and a boy being quite sufficient to manage five looms of coarse work, and three or four in fine work.

Mr. Miller's Power-Loom.—A patent was taken out for this in 1796. It is so much like Mr. Austin's in its general principle, that it is unnecessary to enter into the description. The motions are all produced by camms fixed on a horizontal axis, and operate upon a number of horizontal levers, disposed beneath the loom, in the situation of treadles: in other respects the arrangement of the parts is very different. This is sometimes called the wiper-loom, wiper being a different name for a camm.

Crank Loom by Power.—In this the treadles are actuated by cranks, instead of camms or wipers. The reciprocating motion produced by a crank is not uniform, but accelerated at one time, and retarded at another. This is an advantage in some of the operations of a loom. It is true, that, by means of wipers, any required law of acceleration may be produced; but in a crank, the acceleration must proceed according to one law. The superiority of cranks arises

from the circumstance, that they will communicate motion in both directions; whereas a cam will only push a lever in one direction, and the return of the motion must be made by a spring or counterweight. Now, if this counterweight is too large, it makes unnecessary loss of power and friction; and if it is too small, there is some uncertainty in the return of the lever.

Mr. Todd of Boulton had a patent, in 1803, for improvements in power-looms.

Mr. Horrocks of Stockport had three successive patents for this kind of machinery, in 1803, 1805, and 1813. The machine described in the latter is a crank-loom; that is, the lay is actuated by a crank to beat up the weft. The principal improvement consists in a system of levers, which transmit the action of this crank to the lay, and so modify it, that the lay will advance quickly, and give an effective stroke to the weft, and then withdraw quickly to a stationary position, in which it will remain whilst the shuttle is thrown. The advantages which are stated are, that a large shuttle may be used, sufficient to hold a full-sized cop of weft: the waste and loss of time by renewing the cop will, therefore, be less. From the smartness of the stroke, less weight will be required on the yarn-beam, and this will occasion the heddles to work more lightly, so as to break fewer threads. From the same cause, more threads of the weft may be laid in an inch, and make closer work.

Mr. Johnson of Preston had a patent in 1805, and another in 1807, for a power-loom, in which the warp is stretched on a vertical plane, instead of horizontal, as in former machines. The advantages of this are stated to be, 1st, that it takes less space; 2d, the reed serves for the shuttle-race, because the shuttle runs upon the reed itself, and, therefore, makes no friction upon the yarns; 3d, also in dressing, picking, and clearing the warp, the attendant always remains in front of the machine, and can continue to watch the machine; whereas, in the other looms, he must quit his post in front, and go round behind the looms for these operations. When the dressing is to be applied to the warp, whilst it is in the loom, that part of the warp is conducted horizontally for that purpose, and a fan is applied to dry the warp.

The latest inventions of power-looms are Mr. Peter Ewart's patent, 1813; and Mr. Duncan's loom, which he calls a vibrating loom.

The Indian Loom.—This is a striking contrast to our power-looms; it consists merely of two bamboo rollers, one for the warp, and the other for the finished cloth; and a pair of heddles. The shuttle performs the double office of shuttle and reed: for this purpose, it is made like a large netting-needle, and of a length somewhat exceeding the breadth of the piece of cloth which is to be woven.

This apparatus the weaver carries to any tree which affords a shade most grateful to him: under this he digs a hole large enough to contain his legs, and the lower part of the geer or heddles; he then stretches his warp, by fastening his bamboo rollers at a due distance from each other on the turf, by wooden pins; the balances of the geer or heddles he fastens to some convenient branch of the tree over his head; and two loops underneath the geer, in which he inserts his great toes, serve instead of treadles; his long shuttle, which performs also the office of a batten, draws the weft, throws the warp, and afterwards strikes it up close to the web. In such looms as this are made those admirable muslins, whose delicate texture the Europeans can never equal, with all their complicated machinery.

The weaving, even of their finest muslins, is thus conducted in the open air, exposed to all the intense heat of

their climate. We know well that this would be impracticable with fine work in this country, even in an ordinary summer day, on account of the sudden drying of the dressing. It is not known what is the substance which the Indian weavers employ for dressing their warps. It might be of use to our manufacturers, were this investigated in a satisfactory manner. It is said to be a decoction of rice, formed by boiling the rice in a small quantity of water, and expressing the juice: when this is cool, it forms a thick glutinous substance, which undergoes some kind of fermentation before it is used.

Figure-weaving.—Having given an account of the nature and process of plain weaving, we must notice the fanciful and ornamental parts of the business. The extent to which this species of manufacture is carried renders it an object of very great national importance, and deserving a more minute description than our limits will admit.

Figures or patterns are produced in cloth, by employing threads of different colours, or of different appearance, in the warp, or in the weft. By the weaving, the threads must be so disposed, that some colours will be concealed and kept at the back, whilst others are kept in the front; and they must occasionally change places, so as to shew as much of each colour, and as often as it is necessary, to make out the figure or pattern.

The weaver has three means of effecting such changes of colour: First, by using different coloured threads in the warp, or threads of different sizes and substances; these are arranged in the warping, and require no change in the manner of weaving. This is confined to striped patterns, the stripes being in the direction of the length of the piece.

Secondly, by employing several shuttles charged with threads of different colours or substances, and changing one for another every time a change of colour is required. This makes stripes across the breadth of the piece; or, when it is combined with a coloured warp, it makes chequered and spotted patterns of great variety.

Thirdly, by employing a variety of heddles, instead of two, as we have hitherto described; each heddle having a certain portion of the warp allotted to it, and provided with a treadle. When this treadle is depressed, only a certain portion of yarns which belong to that heddle will be drawn up, and the rest will be depressed; consequently, when the weft is thrown, all those yarns which are drawn up will appear on the front or top of the cloth; but in the intervals between them, the weft must appear over those threads which are depressed. The number of threads which are thus brought up may be varied as often as the weaver chooses to press his foot upon a different treadle, and by this he produces his pattern.

All these means may be combined together, and give the weaver the means of representing the most complicated patterns.

The principal varieties of woven cloth, including only those which require a different process for their fabrication, are the following:

Stripes are formed upon the cloth either by the warp or by the weft. When the former of these ways is practised, the variation of the process is chiefly the business of the warper; but in the latter case, it is that of the weaver, as he must continually change his shuttle.

By unravelling any shred of striped cloth, it may easily be discovered whether the stripes have been produced by the operation of the warper or those of the weaver.

When the fly-shuttle is used, the changing of the shuttle is very readily effected by a simple contrivance. One of the shuttle-boxes or troughs, as we have before called them,

(*Plate II. Weaving, fig. 2.*) is made in two parts, so that a part of the trough I near the pecker, where the shuttle lies during the time it is at rest, can be removed, and another trough substituted, which contains a different shuttle. For the purpose of making the change with facility, a moveable shuttle-box *n* is suspended by two perpendicular stems *o* from a wire or centre of motion *m* attached to the lay, as is shewn by the dotted lines. The moveable box is just on the same level with the shuttle-trough I, and is divided by partitions into two or three separate troughs, each exactly the width of the regular trough, and as long as is necessary to contain a shuttle. The pecker *k*, and the wire upon which it slides, remain exactly as before described; but by swinging the moveable box *n* on its centre any one of its compartments may be brought to line with the real place for the shuttle-trough in which the pecker runs. The moveable box must have proper catches to hold it exactly in its true positions.

In working with this contrivance a shuttle of a different colour must be placed in each cell or division of the moveable box *n*; and when the weaver desires to change the shuttle he pulls the connecting string. This moves the shuttle-troughs either backwards or forwards, so as to carry away that shuttle which had been just before in use, and place another before the pecker. Then if he pulls the pecker-handle, the new shuttle will be thrown across the shuttle-race, just as the old one was in the former instance. If only one moveable shuttle-box is used there will be some limitation in the pattern, because the stripes of different colour must always consist of an even number of the same coloured thread, as two, four, six, &c. This may be obviated, and a greater change of shuttles may be introduced, by using two moveable shuttle-boxes, one at each end of the shuttle-race: in that case the two moveable boxes are provided with cranks and strings, so that the weaver can reach either of them with ease.

Checks are produced by the combined operations of the warper and the weaver.

Tweeled cloths are so various in their textures, and so complicated in their formation, that it is difficult to convey an adequate idea of the mode of constructing them without the aid of several drawings.

In examining any piece of plain cloth, it will be observed that every thread of the weft crosses alternately *over* and then *under* every thread of the warp which it comes to; and the same may be said of the warp: in short, the threads of the warp and weft are thus interwoven at every point where they cross each other, and are therefore tacked alternately.

Tweeled cloth is rather different, for only the third, fourth, fifth, sixth, &c. threads cross each other, to form the texture.

Hence two, three, four, or more, of the successive threads or shoots of the weft will be found to pass under or over the same thread of the warp; or, in other words, by tracing any thread of the warp it will be found to pass over two, three, four, or more threads of the woof at once, without any interweaving the warp. Then it crosses and passes between the threads of the weft, and proceeds beneath two, three, four, or more threads, before it makes another passage between the threads of the weft.

Tweeled cloths are of various descriptions, and produce different kinds of patterns; because at all the intersecting points where the threads actually cross or interweave both threads of warp and weft are seen together, and these points are therefore more marked to the eye, even if the warp and weft are of the same colour. These points in plain tweels form parallel lines extending diagonally across the breadth of the cloth, with a different degree of obliquity, according to the

number of weft-threads over or under which the warp-threads pass before an intersection takes place. In the coarsest kinds every third thread is crossed: in finer fabrics they cross each other at intervals of four, five, six, seven, or eight threads; and in some very fine tweeled silks the crossing does not take place until the sixteenth interval.

Tweeling is produced by multiplying and varying the number of heddles, or, as the weavers express it, the number of leaves in the harness, which is the name given to the whole number of heddles employed in a loom; by the use of a back-harness or double-harness, by increasing the number of threads which pass through each split of the reed, and by an endless variety of modes in drawing the yarns through the heddles; also by increasing the number of treadles, and changing the manner of treading them.

The number of treadles requisite to raise all the heddles which must be used to produce very extensive patterns, would be more than one man could manage; for if he placed his foot by mistake on a wrong treadle he would disfigure his pattern. In these cases, recourse is had to a mode of mounting or preparing the loom, by the application of cords to the different heddles of the harness; and a second person is employed to raise the heddles in the order required, by pulling the strings attached to the respective heddles of the back-harness, and each heddle is returned to its first position by means of a leaden weight underneath. This is the most comprehensive apparatus used by weavers, for all fanciful patterns of great extent, and it is called the *DRAW-LOOM*. See that article.

The manner of mounting the harness of looms, to produce all the principal varieties of fabrics, is detailed in our articles *DESIGN*, *DRAUGHT*, and *CORDING of Looms*; also *DAMASK*, *DIAPER*, *DIMITY*, *DORNOCK*, *FUSTIAN*, and *TAPESTRY*. A perusal of those articles will render it unnecessary for us to proceed farther on that subject in the present article. We shall however describe a most valuable invention, which has of late years come into use, as a substitute for the second person or draw-boy, who must be employed in the draw-loom, by which loom alone all the complicated patterns can be woven.

Machine called the Draw-Boy, because it performs the Office of a Draw-Boy in Weaving.—The saving of labour is not the only advantage of this machine; the certainty of its operation and security from mistake are obvious. The weaver produces the required action upon the most complicated harness by two treadles only, which he works alternately, just with the same motion as in plain cloth-weaving. The machine, when once set up, performs every thing else.

Like most other inventions, this was at first imperfect, but has been gradually improved. We do not know its history, but we have seen great numbers of machines, for carpet-weaving and coarse goods, which have been some years in use. The machine is situated in a small square frame, not larger than a chair, which stands at the side of the loom, and cords from all the different heddles are conducted from the draw-loom down to this frame, where they are arranged in order. Each cord has a knot answering to the handle, which the boy must pull in the common draw-loom; and there is a piece of mechanism actuated by the treadles which at every stroke selects the proper cord, and draws it down so as to raise the heddles belonging to it. The next time it changes its position and takes another cord, and so on until the whole number of cords has been drawn and the pattern completed.

These original machines have a great defect, *viz.* that they only proceed with regularity to raise up all the heddles, until all the cords have been drawn, and one series of changes

has been gone through; but when this is completed, and a repetition of the pattern is wanted, the weaver must stop and restore the machine to its original position by pulling a string. This appears very easy, but it diverts his attention; and if he does not do it at the exact moment his pattern may be spoiled. This defect was remedied by Mr. Alexander Duff, who received a small and inadequate premium from the Society of Arts in 1807, probably because they were not aware of its value and importance; but in 1810 we find them with a liberality truly discouraging to real merit, giving an equal reward to another person, for the most trivial alteration of Duff's machine. The latter machine is alone described in their Transactions; see vol. xxviii.

Mr. Duff's Draw-Boy.—Fig. 4. Plate II. Weaving, is a plan of this machine, and fig. 2. a perspective view. It is fixed at the side of a draw-loom, in the same place as a draw-boy would stand, and H shew the cords which are to draw the harness. The same letters are used in both figures. A A is a square wooden axis, mounted so as to turn backwards and forwards in the frame B B, on points or centres of motion. At one end of it a pulley D is fixed, to receive a line *aa* fastened to it at the highest point, by means of which the axis receives motion from the two treadles of the loom, one of the treadles being attached to one end of the line, and the other to the opposite end of it. E E are two rails of wood, fixed across the frame parallel to the axis; and *ee* are two brass plates screwed to the rails, and pierced with a great number of holes to receive as many cords. Each cord is tied by one end to a central rail F of the frame beneath the axis; and after passing through one of the holes in the above plate *e*, and turning over a round wooden rod G, has a lead weight suspended to the other end of it. These weights are shewn at *bb*. The rods G G are suspended by strings at their ends from the ceiling of the room. To each of the above cords another is tied just before it passes over G. These are represented by H, and hang loosely. The upper ends of these cords are tied to horizontal cords extended across the ceiling of the room, and made fast to the ceiling at one end; the other ends pass over pulleys situated at the top of the loom, in a frame called the table of mullets, and the harness or heddles are suspended by them.

By this arrangement it will be seen, that when any one of the cords fastened at F is pulled down, it must draw one of the strings H, and raise such an arrangement of the harness or heddles as is proper to produce the figure which is to be woven. The weight *b* draws the cord so as to keep it straight; all that is therefore necessary is to draw down the cords at F one at a time, but to take a different one each time, and thus raise a different series of the heddles each time; this is the business of the machine, and which it accomplishes in the following manner.

The bar, or axis, A A, has an iron semicircle, *d*, grooved like a pulley, and each of its ends divided, so as to form a cleft-hook or claw.

Each of the strings made fast at F has a large knot tied in it, just beneath where it passes through the brass plate *ee*, and which knot stops the farther ascent of the cord, in consequence of the pull of the weight *b*. Now when the axis A vibrates backwards and forwards by the treadles of the loom, as before mentioned, the hook of the semicircle *d* seizes the knot of one of the cords F, and draws down that cord, and raises the heddles belonging to it. The weaver throws the shuttle, and then returns the treadles, and the axis A with the semicircle returns back again, and allows the cord F to take its original position. When the semicircle *d* inclines over to the other side, its opposite hook

takes hold of the cord F, which is next to the one opposite to that which it just quitted; it draws down this cord, and the weaver again throws his shuttle, then returns the semicircle to the opposite side, and it will take the cord next to the opposite one, and so on; so that the semicircle will in succession take every alternate cord in each of the rows *ee*, and leave every other.

This is effected by the semicircle sliding along its axis A every time, by means of two wooden racks, *b* and *i*, in the plan, which are let into grooves in the axis A; these racks have teeth like saws, but inclined in contrary directions. The racks move backwards and forwards in their grooves, the extent of a tooth at each vibration of the axis, by the action of two circular inclined planes of iron fastened to the frame at L M, against which the ends of the racks are thrown by spiral springs concealed beneath each rack. The semicircle is fixed on a box or carriage N, which slides upon the axis A, and has two clicks upon it; one at *l*, which falls into the teeth of the rack *b*; the other at *m* for the rack *i*: *n* is a roller fixed over the box, and connected with the two clicks *l* and *m*, by threads wound in opposite directions; so that one click is always raised up, and disengaged from its rack, while the other is in action. O is a piece of wire fixed to the frame, so as to intercept a small wire projecting from the roller when the axis is inclined, and turn the roller a small quantity; P is another wire for the same purpose, but fixed to a cross bar, Q, which is moveable, and can be fastened at any required place, farther or nearer from the end of the axis. Suppose the roller *n* to be in such a position that the click *m* is down, and *l* drawn up, the action will be as follows: the semicircle first inclines to the direction of fig. 2., its hook taking down one string; during this motion the end of the rack *i* comes to the inclined part of the circular inclined plane M, and moves by its spring towards D, the space of one tooth, which the click *m* falls into. On the return of the axis, the rack *i* is thrust back, and the box N and semicircle with it towards L, causing the hook to take the next opposite string: in this manner it proceeds, advancing a tooth each vibration, till it gets to the end of its course; the tail of the roller *n* then strikes against the pin P, and turns the roller over, raises the click *m*, and lets down the other, *l*, into the teeth of the rack *b*; this was all the time moving in a contrary direction to *i*, by its inclined plane L, but had no action, as its click *l* was drawn up; this being let down, the semicircle is moved back, a tooth at a time, towards M, until it meets O, which upsets the roller *n*, and sends the semicircle back again.

Tweeled Silks.—In weaving very fine silk tweels, such as those of sixteen leaves, the number of threads required to be drawn through each interval of the reed is so great, that if they were woven with a single reed, the threads would obstruct each other in rising and sinking, and the shed, or opening of the divided warp, would not be sufficiently open to allow the shuttle a free passage. To avoid this inconvenience, other reeds are placed behind that which strikes up the weft; and the warp-threads are so disposed, that those which pass through the same interval in the first reed are divided in passing through the second, and again in passing through the third. By these means the obstruction, if not entirely removed, is greatly lessened.

In the weaving of plain thick woollen cloths, to prevent obstructions of this kind arising from the closeness and roughness of the threads, only one-fourth of the warp is sunk and raised by one treadle, and a second is pressed down to complete the shed between the times when every shot of weft is thrown across.

Double Cloth is composed of two webs, each of which

conflicts of separate warps and separate wefts, but the two are interwoven at intervals. The junction of the two webs is formed by passing each of them occasionally through the other, so that any particular part of both warps will be found sometimes above and sometimes below.

This species of weaving is almost exclusively confined to the manufacture of carpets in this country. The material employed is dyed woollen, and as almost all carpets are decorated with fanciful ornaments, the colours of the two webs are different, and they are made to pass through each other at such intervals as will form the patterns required. Hence it happens that the patterns at each side of the carpet are the same, but the colours are reversed. Carpets are usually woven in the draw-loom, or with the machine called the draw-boy before described.

Marfeilles is a fabric woven of cotton, which is a double cloth. The loom for weaving *Marfeilles* is somewhat similar to the diaper loom. A good idea of the manner in which it is prepared may be had, by conceiving two webs woven one under the other in the same loom, which are made to intermingle at all the depressed lines, and form the reticulations on the surface, in imitation of the quilting performed by hand.

When the species of *Marfeilles*, called *Marfeilles quilting*, is made, a third warp, of softer materials than the two others described, lies between them, and merely serves as a sort of stuffing to the hollow squares formed by them.

Quilting is another sort of cotton stuff, solely appropriated to quilts, which should, in strictness, be set down exclusively to the cotton manufacture, although there is nothing to prevent its being made of other materials.

The weft of those quilts is of very coarse and thick yarn, which is drawn out by a small hook into little loops, as it is woven, that are so arranged as altogether to form a regular pattern; every third or fourth shoot of the shuttle, the weaver has to stop to form those loops from a draft, which causes the weaving of those quilts to take up more time than that of any other stuff, except tapestry; which accounts for the greatness of the price at which they are sold, in proportion to the value of the materials of which they are principally composed.

Gauze differs in its formation from other cloths, by having the threads of the warp crossed over each other, instead of lying parallel. They are turned to the right and left alternately, and each shot of weft preserves the twine which it has received.

This effect is caused by a singular mode of producing the sheds, which cannot easily be described without the aid of drawings.

Cross, or *Net Weaving*, is a separate branch of the art, and requires a loom particularly constructed for the purpose.

Spots, brocades, and lappets, are produced by a combination of the arts of plain, tweeled, and gauze weaving, and as in every other branch of the art are produced in all their varieties by different ways of forming the division of the warp by the application of numerous heddles, and their connections with the treadles which move them. Indeed the great skill of the art consists in the proper management of this part of the apparatus of a loom.

Ribband Weaving.—This was formerly performed by a small common loom, weaving one ribband at a time. Ribbands are commonly striped in the length by laying a striped warp, and patterns are produced by changing the colour of the weft occasionally; sometimes an ornamented edging is formed by a succession of open loops at the borders of the ribband. Figured ribbands are also woven by a great number of treadles, but as they rarely extend to a greater number

than the weaver can manage by his feet, they seldom employ a draw-loom.

Engine-Loom for weaving Ribbands.—The weavers at Coventry, which is the principal seat of the ribband trade, universally employ what they call an engine-loom: it is worked by the hands and feet like a common loom, but weaves twelve, sixteen, or even twenty ribbands at once. The shuttles are of course fly-shuttles, and are driven by what is called a ladder, because it is a small frame exactly like a ladder, which slides horizontally in a groove in the lay; and every cross-bar of the ladder acts upon one shuttle in the manner of a pecker: the ladder has a handle to give it motion.

Another peculiarity of this loom is, that the ribbands are taken away as they are woven, with very few interruptions to wind up the work: for this purpose they conduct the warps over pulleys, and the ribbands also, so that both hang down in long loops. These looped parts are conducted through pulleys, which are loaded with weights, and tend always to draw the loops down, and keep the warp tight. The weight which is thus suspended by the finished ribband tends to draw it forwards at every stroke which the lay makes; and the weight which is suspended by the yarn of the warp is drawn up. When these weights have run through their respective courses, the weaver must stop to wind up the finished ribband, and unwind a fresh length of yarn. In some looms this is rendered unnecessary by a simple mechanism, which continually winds up the ribband as fast as it is woven.

In 1801 the Society of Arts rewarded Mr. Thomas Clulow, for an improved loom for weaving figured ribbands.

This loom differs from the common figured ribband-looms in the method of forming the figure, which, in the old mode, was tedious, from the work being stopped, whilst the figure was drawn by hand.

In the present loom, the tire-cords which form the figure are drawn or worked by a cord or leather-strap fixed to the centre-treadle, which strap passes over two vertical and one horizontal pulley to the back of the loom, and has a weight hung to the end thereof. Upon this strap above the weight is fixed an iron, of a bevel or sloping form, which when the strap is pulled up by pressing with the foot upon the treadle, raises a wire-lever placed across the main-wheel of the movements placed vertically, and allows this main-wheel to move one-fourth of its circumference, where it is stopped by an iron pin, placed on its rim, and prevented from returning by a clutch or catch on the edge of the wheel on its right side.

Within the rim of the main-wheel is a small catch-strap connected with the strap above-mentioned; this catch-strap pulls forward the main-wheel one-fourth of its circumference, until it is stopped by the wire-lever and one of the pins on the rim, of which there are four in number in the ground.

There are also four iron pins projecting from the left side of the main-wheel in opposite quarters of it: these act on a hanging lever, to the lower part of which a string is attached, which passes behind the box containing the whole machinery, and raises four clicks or catches on four rollers, which permits any one of the four rollers to run back as the figure may require, each roller by such motion drawing up the number of threads necessary to form the figure, by cords extending from these rollers over pulleys to the pass-cords, which draw the figure.

Machine Loom for Ribbands.—We have before mentioned M. Vaucanson's loom for weaving ten ribbands by a rotatory motion. We do not know that this is in use in this country.

Mr. James Birch invented an improvement on the swivel-loom, so as to weave satin-guard or figured laces, and received a reward from the Society of Arts in 1804.

This loom is worked by a circular motion of the hands, without treadles, or any application of the feet.

A wooden bar, to which the hands are applied, works two cranks on a large iron axle, extending the width of the loom; one crank is near each end of the above axis. A fly-wheel is attached to one of the ends of the axis, to regulate the motion of the machinery; an endless screw is placed upon the axis, works a star-wheel underneath it, which turns a barrel that has a resemblance to that of a hand-organ, and has wooden pegs fixed in different parts around it: these pegs catch upon levers, which draw forward the cords that form the figure, and pull them down by a claw, which secures the cords thus brought within its power, and by those means raise the upper geer connected with the cords.

In this loom fourteen pieces of satin-guard or bed-lace are wove at the same time, either one pattern and breadth, or all of different patterns and breadths, as may be required. The figure may be extended to any number of shoots desired.

The loom takes up no more space than a common swivel-loom, such as is employed in plain-work. It appears to work with ease and expedition, to make good work, and to be easily managed. It does not break or chafe the silk during its working. The weaver can move to any part of

the front of the loom to inspect the work, and to continue the motion during that time; and the figure or pattern may be formed double the length of those usually done in the engine-loom. The loom can be stopped when required, at any one shoot of the shuttle; and it will answer to weave articles made of silk, wool, cotton, or linen, or mixtures of those articles, or gold or silver lace, and performs its work in half the time of an engine-loom.

The want of uniformity in the technical phraseology of the art of weaving, and the intricacy of the subject, have compelled us to render our descriptions far more intricate and difficult than they otherwise would have been.

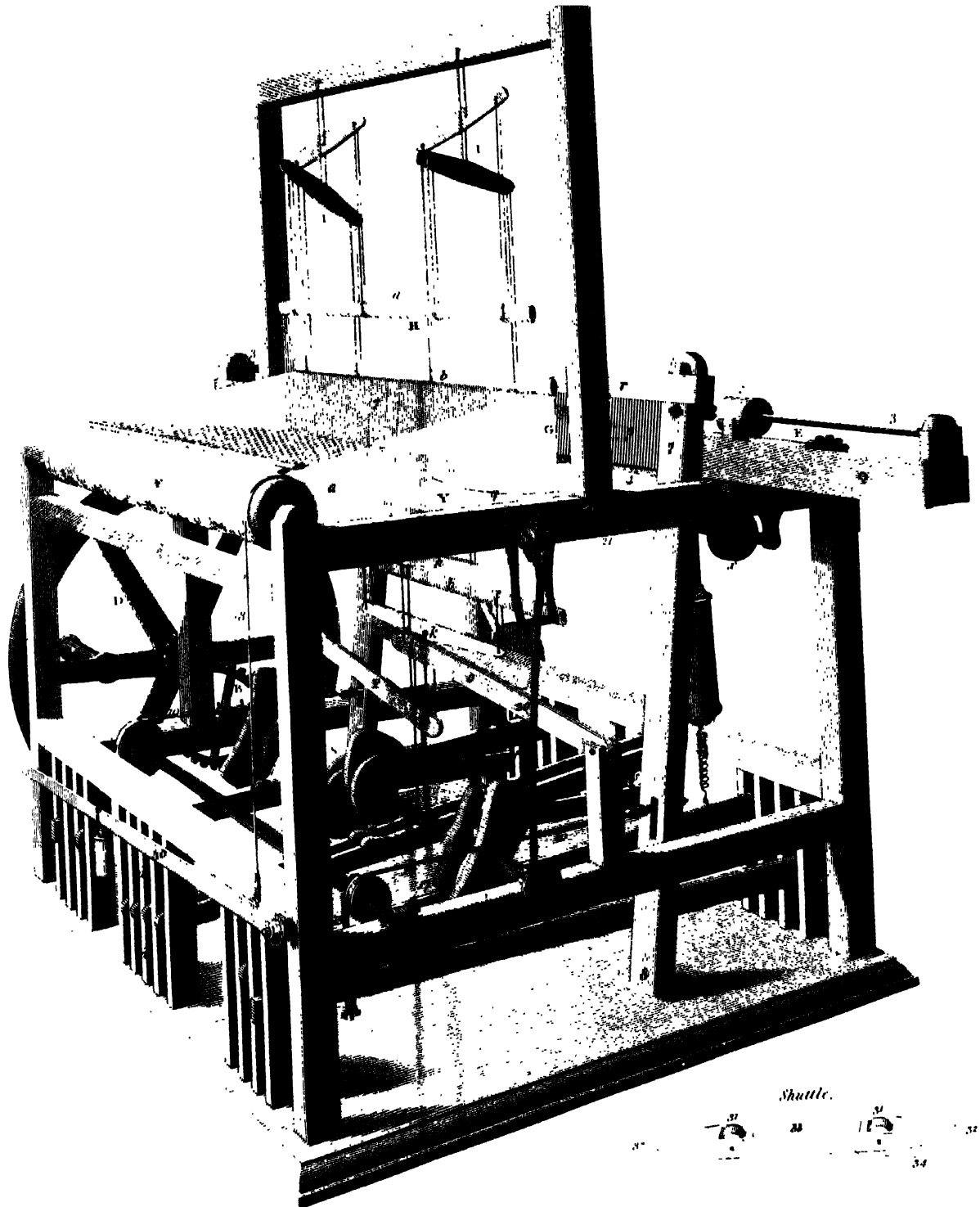
We must acknowledge the assistance which we have derived from the very excellent "Essays on the Art of Weaving," by Mr. Duncan, 1808, in 2 vols. 8vo. It is a most curious and valuable publication, embracing almost every thing necessary to be known concerning the art on which it professes to treat; if we except some of the recent improvements in machine-weaving, which are only slightly noticed.

The French have long excelled in the various branches of figure-weaving; but this is more from dexterity of their weavers than from their machinery. Descriptions and drawings of all looms used by them, with every detail of their structure, will be found in the different articles of *L'Encyclopede Methodique*, and *Les Arts et Metiers*, *D'Art de Fabriquer le Soie*, &c.

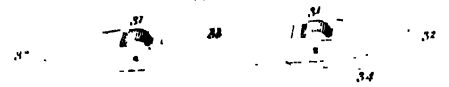
WEAVING.

PLATE 1.

M^r Austin's Engine Loom.



Shuttle.



Published as the steel engravings by Longman, Hurst, Rees, Orme & Brown, Paternoster Row, London

Wedgwood

WEDGWOOD, JOSIAS, in *Biography*, was the younger son of a Staffordshire potter, and born in July 1730. His education was restricted, but his mental powers were of a superior kind, so that by the fixed and persevering exercise of them he made very considerable improvement in the art of pottery to which his attention was directed, and gave a name as well as reputation to the place of his nativity. (See POTTERY and THE POTTERIES.) His patrimony was small, but by his super-eminent skill and steady application he was the founder of his own fortune as well as fame. The principal seat of the potteries of Staffordshire was Burslem; and there is reason to believe that they have existed in or near this place for many centuries, and even, as some say, since the time of the Romans. But they had continued for a long time in the same rude state in which Plot found them when he surveyed this county. The merit of introducing into this country improvements in the art of pottery must be ascribed to two brothers of the name of Eders, who came hither from Holland about the year 1700, and settled

in the neighbourhood of the Staffordshire potteries. They manufactured a red unglazed porcelain from a clay, which they found in the estate on which they settled, called "Bradwell;" but this was only the brown stone ware, in the composition of which no flint is used; but they made use of salt in glazing it: this salt, or muriate of soda, was thrown into the oven at a certain stage of the firing process, and the pieces of ware were so disposed as to receive the fumes of it on every part of their surfaces. The fumes, however, occasioned an alarm in the neighbourhood, which obliged them to leave the country. A similar manufactory, however, was soon after established at Shelton, in the Potteries, by one of their workmen, whose name was Astbury, and who had possessed himself of their secret; and as it was found very useful, it was tolerated by the inhabitants, though on the day of glazing, the dense offensive fumes from fifty or sixty manufactories filled the valleys, and covered the hills through an extent of several miles. The white stone ware,

and the use of ground flints in pottery, were introduced at a later period, and, as it is said, (see Parkes's Chem. Catechism,) in consequence of the following incident. About the year 1720, a potter, supposed to be the above-mentioned Astbury, stopped at Dunstable in his way to London, and sought a remedy for a disorder in his horse's eyes; and the ostler of the inn by burning a flint stone reduced it to a fine powder, which he blew into them. The potter, observing the beautiful white colour of the flint after calcination, instantly thought of applying the discovery to the improvement of his art, and afterwards introduced the white pipe-clays found on the south side of Devonshire, instead of the iron-clays of his own country, and thus produced the white stone ware. At first the flints were pulverized to the great injury of the persons employed; till the famous Brindley, in the early period of his life, constructed the mills that are now used for grinding them in a moist state. It is farther said, that an ingenious mechanic, named Alfager, afterwards improved the construction of the potter's wheel, so as to give much greater precision and neatness to the work. But still the French pottery exceeded in beauty that of Staffordshire; and about the year 1760, a considerable quantity of it was imported, and purchased by persons of opulence to the great detriment of the English manufacture. Mr. Wedgwood directed his attention to this article, and made several improvements with regard to the forms, colours, and composition of his manufacture; and in the year 1763 invented a kind of ware for the table, which gave a turn to the market, and under the name of queen's ware, conferred upon it in consequence of the patronage of her majesty, came into very general use. Its materials were the whitest clays from Devonshire and Dorsetshire, mixed with ground flint, and covered with a vitreous glaze. By varying and repeating his experiments, Mr. Wedgwood discovered the mode of manufacturing other species of earthenware and porcelain, excellent and beautiful, and adapted to various purposes both of use and ornament. With a view of prosecuting his improvement in pottery he applied to the study of chemistry, and for his farther assistance engaged the ingenious Mr. Clussholme, who had been employed in a similar department by the celebrated Dr. Lewis, author of the "Commercium Philosophico-Technicum;" for whom he not only built a comfortable habitation near the manufactory, but liberally afforded him an annuity for his support under the decays of age, which he continued till his death. Aided also by the classical taste of his partner, Mr. Bentley, potteries were furnished which served as models for various articles, formed of other materials, that were held in high estimation. We learn from Dr. Bancroft, that almost all the finely diversified colours which Mr. Wedgwood applied to his pottery were produced only by the oxyds of iron. In the manufacture of his beautiful jasper ware, which rivalled the productions of antiquity, and which found its way into the collections of the curious in all parts of Europe, he employed the native sulphate of barytes, and from this use of it he derived great profit, until by the infidelity of a servant the secret was disclosed and sold, so that others employed inferior workmen at a reduced salary, and thus prevented Mr. W. from employing his exquisite modellers on that branch of the manufacture.

Among other curious productions of this inventive manufacturer we may mention his imitation of the Barberini or Portland vase, which was discovered in the tomb of Alexander Severus, and for which the late dukes of Portland paid 1000 guineas. The subscription for Mr. W.'s manufacture was at the rate of 50*l.* each for fifty vases, but such

were the expenses of its execution, that the partners lost money by the undertaking. Mr. Webber, it is said, received 500 guineas merely for modelling it. See VASE.

We cannot forbear in this connection noticing two cameos of Mr. Wedgwood's manufacture; one of a slave in chains, of which he distributed many hundreds, with a view of exciting the humane to assist in the abolition of the slave-trade; and the other a cameo of Hope, attended by Peace and Art and Labour, which was made of argillaceous earth from Botany Bay, to which place he sent many of them, in order to shew what their materials were capable of, and to encourage the industry of the inhabitants.

To this brief account of some of the numerous productions of Mr. Wedgwood, we shall subjoin the tribute paid to his industry and genius by an elegant modern poet:

"Gnomes! as you now dissect with hammers fine
The granite rock, the noduled flint calcine;
Grind with strong arm, the circling chert betwixt,
Your pure kaolins and petuntzes mixt;
O'er each red faggar's burning cave preside,
The keen-eyed fire-nymphs blazing by your side;
And pleased on Wedgwood ray your partial smile,
A new Etruria decks Britannia's isle.
To call the pearly drops from Pity's eye;
Or stay Despair's disanimating sigh,
Whether, O Friend of Art! the gem you mould
Rich with new taste, with ancient virtue bold;
Form the poor fetter'd slave on bended knee
From Britain's sons imploring to be free;
Or with fair Hope the brightening scenes improve,
And cheer the dreary wastes of Sydney-cove;
Or bid Mortality rejoice and mourn
O'er the fine forms on Portland's mystic urn.
Whether, O Friend of Art! your gems derive
Fine forms from Greece, and fabled gods revive;
Or bid from modern life the portrait breathe,
And bind round Honour's brow the laurel wreath;
Buoyant shall sail, with Fame's historic page,
Each fair medallion o'er the wrecks of age;
Nor Time shall mar, nor Steel, nor Fire, nor Rust,
Touch the hard polish of the immortal bust."

The demand for Staffordshire ware very much increased, and it became a commercial article of exportation of very considerable value.

The district which Mr. Wedgwood inhabited became by his means the seat of population and abundance. The vicinity was enriched, and a new canal of importance, called the Grand Trunk canal, and connecting the Trent and the Mersey, was obtained and executed by his influence. The ample fortune which he acquired was liberally enjoyed, and benevolently applied to many purposes of private charity and public utility. Chemistry and the arts in their mutual connection were objects of his attention; and he contrived an instrument for measuring high degrees of heat, called a pyrometer, of which he gave an account in the Phil. Transf. for 1782, 1784, and 1786. See THERMOMETER.

The disposition and manners of Mr. Wedgwood were no less estimable than the powers of his mind; so that he was as much the object of admiration and esteem for his moral as for his intellectual qualities. So much was he respected, and so desirable was the continuance of his useful life, that he died, universally regretted, at his house in Staffordshire, to which he gave the name of Etruria, in January 1795, in the 65th year of his age. Aikin's Chem. Dict. Gent. Mag. Parkes's Chemical Catechism. Parkes's Essays.

Weld

WELD, or WOLD, *reseda luteola* of Linnæus, a plant used by the dyers to give a yellow colour; and for this reason called, in Latin, *luteola*, of *luteus*, yellow. For the characters, see RESEDA.

When the plants are pulled, they may be set up in small handfuls to dry in the field, and when dry enough, tied up in bundles and housed dry; care being taken to house them loosely, that the air may pass between them to prevent their fermenting. That which is left for seeds should be pulled as soon as the seeds are ripe, and set up to dry, and then beat out for use; for if the plants are left too long, the seeds will scatter. Mortimer and Miller.

Weld is much cultivated in Kent, for the use of the London dyers.

Mr. Hellot observes, in his *Art de Teindre*, that for dyeing with weld, the best proportions of alum and tartar for the preparatory liquor are four parts of alum, and one of tartar, to sixteen of the wool; the quantity of the tartar being determined by the greater or less brightness of colour proposed; and that the wool, thus prepared, is to be boiled again with three or four parts of weld to one of wool, but often much less: that for light shades, it is customary to diminish the alum, and omit the tartar; and that, in this case, the colour is more slowly imbibed, and proves less durable.

With a view to economy, the weaker shades of colour are dyed in the same bath, after the stronger are finished. A golden yellow, more or less orange, is given by a weak madder bath, after the welding.

Silk is dyed of a golden-yellow, generally with weld alone, according to the following process: the stuff is first boiled in soap-water, alumed and washed, then passed twice through a weld bath, in which, the second time, some alkali is dissolved, which gives a rich golden hue to the natural yellow of the weld. The colour is further deepened by a little annatto. The solutions of lime with weld give to silk

a bright clear yellow. In order to dye cotton yellow, Berthollet directs first to cleanse it with wood ashes and water, to rinse, alum, and dry without further rinsing, and then to pass it through a yellow bath, in which the weld is somewhat more than the weight of the cotton. When the colour has sufficiently taken, the cotton is thrown into a bath of sulphate of copper and water, and kept there for an hour; after which it is boiled with white soap-water, and, lastly, washed and dried. In order to obtain a deeper jonquil-yellow, the aluming is omitted, and, instead of this operation, a little verdigrise is added to the weld bath, and the cotton finished with soda.

Weld is particularly preferred to all other substances in giving the lively green lemon-yellow. It is, however, expensive; and it is also found to degrade and interfere with madder colours more than other yellows. We may here add, that the fine delicate yellow, obtained from weld, is much used by the London paper-stainers, and sold in the form of hard lumps, consisting chiefly of chalk saturated with the colouring matter. Messrs. Collard and Fraser have given the following improved process:—Diffuse any quantity of fine whiting in boiling water; add to it one ounce of alum for every pound of whiting, which will occasion a brisk effervescence, and stir these materials well together till the gas is wholly disengaged. On the other hand, boil in a separate vessel some weld with water just sufficient to cover it, for fifteen minutes, filter the yellow decoction, and then mix it with the whiting and alumine in such proportions, that the earths may appear to be saturated with the colouring matter. Then let the mixture remain a day at rest, and at the bottom will be the precipitated earth firmly united with the colour, and of a fine yellow tinge, which may be conveniently dried on chalk-stones.

The weld yellow is a water colour, and is never mixed with oil.

Welding

WELDING, in the *Manufactures*, denotes the forging of iron, when intensely heated; or, more generally, the intimate union which subsists between the two surfaces of two pieces of malleable metal, when heated almost to fusion, and hammered. This union is so strong, that when two bars of metal are properly welded, the place of junction is as strong relatively to its thickness as any other part of the bar. Welding heat is the heat necessary for producing this effect. Bar-iron cannot be welded to another piece of iron, unless both be heated to nearly 60° of Wedgwood's pyrometer, which is equal to 8.877 of Fahrenheit's scale, and is called the welding heat; but if cast-steel be heated to this point, it would be fused, and run from under the hammer; and, therefore, it was for a long time thought to be impossible to use it in conjunction with iron, in the same manner as the other kinds of steel are employed. But sir Thomas Frankland at length discovered, that if the cast-steel be made only of a white heat, and the iron of a welding heat, the steel will then be soft enough to unite with the iron, and yet the former will not become fluid by the operation. It will, however, be proper to give the necessary temperatures to the two metals separately, and then to unite them at one single heat. (Phil. Transf. for 1795, p. 296.) Mr. Parkes

observes, that some nicety is required in the process of welding iron, so that the outside of the weld does not oxidize too much and fly off in scales, before the inside is brought up to a welding heat. When, therefore, a skilful workman is about to weld two pieces of iron, he carefully observes the progress of the heat; and if one becomes too hot, he rolls it in sand to preserve it from the action of the atmosphere; and when one piece acquires the necessary temperature before the other, he covers that with sand, whilst he is bringing the corresponding piece up to a sufficient heat for its uniting properly with the former. Silica, when mixed with the oxyd of iron, forms a very fusible compound, which covers the work under operation, and prevents a further oxidation of the metal. Iron and platina are capable of a firm union by welding. See sir John Hall's Experiments, in vol. vi. of Edinb. Phil. Transf. p. 71. Parkes's Essays, vol. iv.

WELDING, the proper heat smiths give their iron in the forge, in order to double up the same, when wanted to weld a work in the doublings, so as to be in one piece thick enough for the purpose it is wanted for.

WELDING-Heat is the strong heat, when the iron is prepared to bind.

Wheel

WHEEL, ROTA, in *Mechanics*, a simple machine, consisting of a round piece of wood, metal, or other matter, which revolves on an axis.

For an account of the *wheel* and *axle*, as a mechanical power, see **AXIS** in *Peritrochio*, and **MECHANICAL POWERS**.

The wheel is one of the principal mechanic powers. It has place in most engines: in effect, it is of an assemblage of wheels that most of our chief engines are composed. Witness clocks, mills, &c.

Its form is various, according to the motion it is to have, and the use it is to answer. By this it is distinguished into *simple* and *dented*.

WHEELS, Simple, are those whose circumference and axis are uniform, and which are used singly, and not combined. Such are the wheels of carriages, which are to have a double motion; the one circular about their axis; the other rectilinear, by which they advance along the road, &c. which two motions they appear to have; though, in effect, they have but one: it being impossible the same thing should move, or be agitated, two different ways at the same time.

This one is a spiral motion; as is easily seen, by fixing a piece of chalk on the face of a wheel, so as that it may draw a line on a wall, as the wheel moves. The line it here traces is a just spiral, and still the more curve, as the chalk is fixed nearer the axis.

The fact, however, has been disputed; and it has been alleged, that nothing is more easy than for any one, who will take the trouble to make the experiment, to prove its falsehood. Place the chalk on the face of the wheel, as directed, and you will find that, so far from its describing a just spiral, and that still the more curve as the chalk is fixed nearer the axis, the chalk, if placed on the periphery of the wheel, will describe a cycloid, and the nearer it is placed to the axis, the nearer will the line it describes approach to the straight line which is described by the axis itself. Moreover, it is not true, nor pretended to be so, that the same thing moves two ways at once in the rectilinear and circular motion of wheels. The local motion, or motion of the whole wheel, is rectilinear only; that of the parts of the wheel circular. Nor can this latter motion with any propriety be called that of the wheel, unless the same thing could also move quick and slow at the same time, which the different parts of the wheel, in revolving round its axis, evidently do. Jacob's *Obs.* on the Structure and Draught of Wheel-Carriages, 1773, p. 28, &c.

For a very nice phenomenon, in the motion of these wheels, see *ROTA Aristotelica*.

We shall add, that, in wheels of this kind, the height should always be proportioned to the stature of the animal that draws or moves them. The rule is, that the load and the axis of the wheels be of the same height with the power that moves them; otherwise the axis being higher than the beast, part of the load will lie upon him; or, if it be lower, he pulls to disadvantage, and must exert a greater force. Though Stevinus, Dr. Wallis, &c. shew, that, to draw a vehicle, &c. over waste uneven places, it were best to fix the traces to the wheels somewhat lower than the horse's breast. See **WHEELS** of *Coaches*, &c.

The power of these wheels results from the differences of the radii of the axis, and circumference. The canon is this: "As the radius of the axis is to that of the circum-

ference, so is any power to the weight it can sustain hereby."

This is also the rule in the axis in *peritrochio*; and, in effect, the wheel, and the axis in *peritrochio*, are the same thing; only, in theory, it is usually called by the latter name, and in practice by the former.

WHEELS, Dented, are those either whose circumference, or axis, is cut into teeth, by which they are capable of moving and acting on one another, and of being combined together.

The use of these is very conspicuous in clocks, jacks, &c.

The power of the dented wheel depends on the same principle as that of the simple one. It is only that to the simple axis in *peritrochio*, which a compound lever is to a simple lever.

Its doctrine is comprised in the following canon; *viz.* "The ratio of the power to the weight," in order for that to be equivalent to this, "must be compounded of the ratios of the diameter of the axis of the last wheel to the diameter of the first; and of the ratio of the number of revolutions of the last wheel, to those of the first, in the same time." But this doctrine will deserve a more particular explanation.

1. Then, if the weight be multiplied into the product of the radii of the axes, and that product be divided by the product of the radii of the wheels, the power required to sustain the weight will be found. Suppose, *e. gr.* the weight *A* (*Plate XL. fig. 83. Mechanics*,) = 6000 pounds, *BC* = 6 inches, *CD* = 34 inches, *EF* = 5 inches, *EG* = 35 inches, *HI* = 4 inches, *HK* = 27 inches: then will $BC \times EF \times HI = 120$; and $CD \times EG \times HK = 32130$. Hence the power required to sustain the weight, will be $6000 \times 120 \div 32130 = 22\frac{1}{2}$ very nearly; a small addition to which will raise it.

2. If the power be multiplied into the product of the radii of the wheels, and the factum be divided by the product of the radii of the axes; the quotient will be the weight which the power is able to sustain. Thus, if the power be $22\frac{1}{2}$ pounds; the weight will be 6000 pounds.

3. A power and weight being given, to find the number of wheels, and in each wheel the ratio of the radius of the axis, to the radius of the wheel; so as that the power, being applied perpendicularly to the periphery of the last wheel, may sustain the given weight.

Divide the weight by the power; resolve the quotient into the factors which produce it. Then will the number of factors be the number of wheels; and the radii of the axes will be to the radii of the wheels, as unity to the several wheels. Suppose, *e. gr.* a weight of 3000 pounds, and a power of 60, the quotient of the former by the latter is 500, which resolves into these factors, 4. 5. 5. 5. Four wheels are, therefore, to be made; in one of which, the radius of the axis is to the radius of the wheel, as 1 to 4; in the rest, as 1 to 5.

4. If a power move a weight by means of two wheels, the revolutions of the slower wheel are to those of the swifter, as the periphery of the swifter axis is to the periphery of the wheel that catches on it.

Hence, 1. The revolutions are as the radius of the axis *FE* to the radius of the wheel *DC*. 2. Since the num-

ber of teeth in the axis FD , is to the number of teeth in the circumference of the wheel M , as the circumference of that to the circumference of this; the revolutions of the slower wheel M , are to the revolutions of the swifter N , as the number of teeth in the axis to the number of teeth in the wheel M , which it catches.

5. If the factum of the radii of the wheels GE , DC , be multiplied into the number of revolutions of the slowest wheel, M , and the product be divided by the factum of the radii of the axes which catch into them, GH , DE , &c. the quotient will be the number of revolutions of the swiftest wheel O . *E. gr.* If $GE = 8$, $DC = 12$, $GH = 4$, $DE = 3$, and the revolution of the wheel M be 1; the number of revolutions of the wheel O will be 8.

6. If a power move a weight by means of divers wheels, the space passed over by the weight, is to the space of the power, as the power to the weight. Hence, the greater the power, the quicker is the weight moved; and *vice versa*.

7. The spaces passed over by the weight and the power, are in a ratio compounded of the revolutions of the slowest wheel, to the revolution of the swiftest; and of the periphery of the axis of that, to the periphery of this. Hence, since the spaces of the weight and the power are reciprocally as the sustaining power is to the weight; the power that sustains a weight will be to the weight, in a ratio compounded of the revolutions of the slowest wheel, to those of the swiftest, and of the periphery of the axis of that, to the periphery of this.

8. The periphery of the axis of the slowest wheel, with the periphery of the swiftest wheel, being given; as also the ratio of the revolutions of the one, to those of the other; to find the space which the power is to pass over, while the weight goes any given length.

Multiply the periphery of the axis of the slowest wheel into the antecedent term of the ratio, and the periphery of the swiftest wheel into the consequent term; and to these two products, and the given space of the weight, find a fourth proportional: this will be the space of the power. Suppose, *e. gr.* the ratio of the revolutions of the slowest wheel, to those of the swiftest, to be as 2 to 7, and the space of the weight 30 feet; and let the periphery of the axis of the slowest wheel be to that of the swiftest, as 3 to 8: the space of the power will be found 280. For $2 \times 3 : 7 \times 8 :: 30 : 280$.

9. The ratio of the peripheries of the swiftest wheel, and of the axis of the slowest; together with the ratio of their revolutions, and the weight, being given: to find the power able to sustain it.

Multiply both the antecedents and the consequents, of the given ratios into each other, and to the product of the antecedents, the product of the consequents, and the given weight, find a fourth proportional: that will be the power required. Suppose, *e. gr.* the ratio of the peripheries 8 : 3; that of the revolutions 7 : 2, and the weight 2000; the power will be found 2147. For $7 \times 8 : 2 \times 3 :: 2000 : 2147$. After the same manner may the weight be found; the power, and the ratio of the peripheries, &c. being given.

10. The revolutions the swiftest wheel is to perform while the slowest makes one revolution, being given; together with the space the weight is to be raised, and the periphery of the slowest wheel; to find the time that will be spent in raising it.

Say, As the periphery of the axis of the slowest wheel is to the given space of the weight; so is the given number of revolutions of the swiftest wheel to a fourth proportional:

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which will be the number of revolutions performed while the weight reaches the given height. Then, by experiment, determine the number of revolutions the swiftest wheel performs in an hour; and, by this, divide the fourth proportional found before. The quotient will be the time spent in raising the weight. Wolf. Elem. Math. tom. ii. p. 214, &c.

WHEELS of a Clock, &c. are the crown wheel, contrate wheel, great wheel, second wheel, third wheel, striking wheel, detent wheel, &c. See CLOCK and WATCH.

WHEELS of Coaches, Waggon, &c. With respect to these, the following particulars are collected from the experiments and reasonings of Camus, Defaguliers, Beighton, Ferguson, Brewster, &c.

1. The use of wheels, in the draught of carriages, is two-fold; *viz.* that of diminishing, or of more easily overcoming the resistance arising from the friction of the carriage, and that of more readily surmounting obstacles, which form angular prominences on the plane over which they are drawn, and which must be either depressed by the weight of the carriage, or render it necessary for the carriage, with its load, to be lifted over them. They serve in their first use to transfer the friction from the under surface of the carriage, and the plane supporting it, to the surfaces of the axle and nave of the wheel. The common method of accounting for this advantage is by saying, that the resistance, arising from friction in planes of equal asperity, increases with the velocity of the motion; so that this velocity must be compared with that of the power necessary to move the machine, and overcome the friction; and it is obvious, at the same time, that the velocity of a circular motion diminishes gradually from the circumference to the centre. See FRICTION.

But to this position it has been objected, that the illustration is not applicable to the case: for, granting that, in the friction of sledges or flat surfaces, the resistance increases in proportion to the velocity of their motion, this is not a parallel case with that of a circular surface rolling over a flat plane. On the contrary, the velocity of motion, in the outer surface of a wheel, is greater than that of its nave, moving under the axle; while at such outer surface there is little or no friction at all; whereas at the nave, moving much slower, there is much more. Indeed, the friction, which the wheel would have against its supporting plane, if it did not turn round its axis, is by its turning round transferred almost wholly to the axis and nave; whose circular motion is notwithstanding so much slower. It is, indeed, notorious, that the great friction of the wheels of carriages lies between the axle and nave; and how then can it be properly asserted, that such friction is diminished at the axle, as the velocity of the circular motion is there diminished? Accordingly it has been alleged by a late writer, that friction is not diminished by the use of wheels, but merely transferred from the outer surface of the wheel to its nave and axle; and that in the case of a wheel rolling along the ground, the spokes act only as single levers, to overcome the friction of the periphery against the plane of its support, the prominences, constituting the roughness of the plane over which it moves, being the fulcra upon which they turn, and not the common centre of these spokes, as others have maintained, who say that the wheel acts, in overcoming friction, as an axis in peritrochio. However, in obviating the friction of the wheels in loaded carriages, their spokes act as double levers, resting on a fulcrum at each end. See the author's method of illustrating and evincing these principles, in Jacob's Obs. on Wheel-Carriages, p. 23, &c.

If carriages were to move along smooth horizontal planes,

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wheels would be useful only in overcoming friction; but as they are drawn along roads covered with loose stones, indented with cavities, they are farther useful in serving to depress, or raise the carriage over the one, and in raising it out of the other.

2. The wheels of all carriages ought to be exactly round; and the felloes should be at right angles to the naves, according to the inclination of the spokes, *i. e.* the plane of the curvature of the wheel should cut the nave at right angles, though it need not pass through the place where the spokes are inserted into the nave.

3. The spokes, according to Mr. Ferguson and most other writers on mechanics, should be inclined to the naves, so that the wheels may be dishing or concave. If, indeed, the wheels were always to go upon smooth and level ground, it would be best to make the spokes perpendicular to the naves, or at right angles with the axles; because they would then bear the weight of the load perpendicularly, which is the strongest way for the wood. But because the ground is generally uneven, one wheel often falls into a cavity or rut, when the other does not, and then it bears much more of the weight than the other does; in which case dishing wheels are best, because the spokes become perpendicular in the rut, and therefore have the greatest strength when the obliquity of the road throws most of its weight upon them; whilst those on the high ground have less weight to bear, and therefore need not be at their full strength. Besides, by this form of the wheels, the base of the carriage is extended, and it is thus prevented from being easily overturned, and the felloes are hindered from rubbing against the load or the sides of the cart. Dr. Brewster, however, is of opinion, that the disadvantages of concave wheels overbalance their advantages. Mr. Antice also, in his "Treatise on Wheel-Carriages," whilst he recommends concave wheels, candidly allows, that some disadvantages attend this construction of them; for the carriage thus takes up more room on the road, so that it is more unmanageable; and when it moves upon plane ground the spokes not only do not bear perpendicularly, by which means their strength is lessened, but the friction upon the nave and axle is made unequal, and so much the more as they are the more dished. Dr. Brewster farther shews, that they are more expensive, more injurious to the roads, more liable to be broken by accidents, and less durable in general, than those wheels in which the spokes are perpendicular to the naves. From these and other considerations, our author is decidedly of opinion, that if wheels are to be composed of naves, spokes, and felloes, the rim should be cylindrical, and the spokes perpendicular to the naves; whereas in concave wheels, the rims are uniformly made conical, which subjects them to a variety of disadvantages. Every cone that is put in motion upon a plane surface will revolve round its vertex, and if force is employed to confine it to a straight line, the smaller parts of the cone will be dragged along the ground, and the friction greatly increased. Now when a cart moves upon conical wheels, one part of the cone rolls while the other is dragged along, and though confined to a rectilinear direction by external force, their natural tendency to revolve round their vertex occasions a great and continued friction upon the linch-pin, the shoulder of the axle-tree, and the sides of deep ruts.

Dr. Brewster has made some farther observations on the construction of certain parts of the wheels. The iron plates, he says, of which the rims are composed, should never be less than three inches in breadth, as narrower rims sink deep into the ground, and therefore injure the roads and fatigue the horses. See the sequel of this article.

4. The axles of the wheels ought to be perfectly straight, and at right angles to the shafts, or to the pole. When the axles are straight, the rims of the wheels will be parallel to each other, and then they will move the easiest, because they will be at liberty to go on straight forwards. But in the usual way of practice, the axles are bent downwards at their ends; which brings the sides of the wheels next the ground nearer to one another than their higher sides are; and this not only makes the wheels to drag sideways as they go along, and gives the load a much greater power of crushing them than when they are parallel to each other, but also endangers the overturning of the carriage when any wheel falls into a hole or rut, or when the carriage goes on a road which has one side lower than the other, as along the side of a hill. Thus, in the hind view of a waggon or cart, let A E and B F (*Plate XL. fig. 9. Mechanics*) be the great wheels parallel to each other, on their straight axle K, and H C I the carriage loaded with heavy goods from C to G. Then as the carriage goes on in the oblique road A a B, the centre of gravity of the whole machine and load will be at C; and the line of direction C d D falling within the wheel B F, the carriage will not overset. But if the wheels be inclined to each other at the ground, as A E and B F are (*fig. 10.*), and the machine be loaded as before from C to G, the line of direction C d D falls without the wheel B F, and the whole machine tumbles over. When it is loaded with heavy goods which lie low, it may travel safely upon an oblique road, so long as the centre of gravity is at C (*fig. 9.*), and the line of direction C d D falls within the wheels; but if it be loaded high with lighter goods from C to L (*fig. 11.*), the centre of gravity is raised from C to K, which shews the line of direction K k without the lowest edge of the wheel B F, and then the load oversets the waggon. Mr. Beighton has offered several reasons to prove, that the axles of wheels ought not to be straight: for which we must refer to *Defaguliers' Exp. Phil.* vol. ii. Appendix, p. 540, &c. Moreover, if the axle were not at right angles to the pole or shaft, but this was on one side, then the coach or carriage would be drawn on one side, and almost all the weight would bear upon one horse. With some mechanics, it is a practice to bend the ends of the axle-trees forwards, and thus make the wheels wider behind than before. Mr. H. Beighton maintains, that wheels in this position are more favourable for turning; since, when the wheels are parallel, the outermost would prefs against the linch-pin, and the innermost would rub against the shoulder of the axle-tree. In rectilinear motions, however, these converging wheels occasion a great deal of friction, both on the axle and the ground, and must therefore be more disadvantageous than parallel ones. This fact is allowed by Mr. Beighton: but he seems to found his opinion upon this principle; that as the roads are seldom straight lines, the wheels should be more adapted to a curvilinear than to a rectilinear motion.

5. Large wheels are always more advantageous for rolling than small ones, in any case, or upon any ground whatever. If we consider wheels with regard to their friction upon the axles, it is evident, that small wheels must turn as much oftener round than the large ones, as their circumferences are less; and, therefore, a wheel which is twice as large as another will have twice the advantage in respect of the friction, the holes of the naves and axles, and the weights upon them, being equal. Again, if we consider the wheels as they sink into the earth, or fall into holes, the bearing of the great wheel being double that of the small one, it would sink but half so deep; and if the small wheel should meet with a hole of the same diameter with itself, it would wholly sink in, whilst only a segment less than half of the great

wheel would fall in: the same thing would also happen in marshy ground, where the small wheel would sink wholly in the same hole which the great one would sink into but in part. The large wheel would also have the advantage of a small one in rising over eminences or rubs that occurred; so that the former would go over rubs much higher than the latter; and indeed over any eminences, provided their height be not equal to its semidiameter. Defaguliers has reduced this matter to a mathematical calculation, in his *Exp. Phil.* vol. i. p. 171, &c.

A late writer has also proved, that a wheel of eight feet diameter has somewhat more than twice the advantage in overcoming obstacles of a wheel of two feet; and he found, in practice, that if it requires a certain power to draw a carriage of a certain weight over a certain obstacle, with wheels of any determinate diameter, it will require wheels of four times that diameter, to draw the same carriage over the same obstacle with half that power. This writer also observes, that, in the draught of carriages ascending inclined planes, the moving power acts not only against the vis inertiae, which is always equal to the absolute gravity of the load, but also against its relative gravity, which increases with the inclination of the plane; and with respect to carriages raised on wheels, it is to be observed, that the higher the axle is removed from the plane, the farther is the centre of gravity removed out of the perpendicular line of support; so that the lower the wheel, the less is the relative gravity of the carriage. Hence he infers, that supposing the friction of two carriages of equal weight, but of different sized wheels, to be equal, the low-wheeled one would be drawn up hill, on a smooth plane, much more easily than the high-wheeled one; though on a smooth, horizontal plane, the latter would be drawn more easily than the former. On the contrary, in going down hill, the high-wheeled carriage will be urged forward, by its relative gravity, more than the low-wheeled one. Jacob, *ubi supra*, p. 63, &c.

It appears, therefore, that the larger wheels are, the more advantageous they are in proportion, provided that they are not more than five or six feet in diameter; for when they exceed these dimensions, they become heavy; or if they are made light, their strength is proportionably diminished, and the spokes, being long, are more liable to break: besides, horses applied to such wheels, would be incapable of exerting their utmost strength, by having the axles higher than their breasts, so that they would draw downwards; as in small wheels the draught is made more difficult, by the horses drawing upwards.

It is observed by Dr. Brewster, in the appendix to his edition of "Ferguson's Mechanics," that when the wheels of carriages either move upon a level surface, or overcome obstacles which impede their progress, they act as mechanical powers, and may be reduced to levers of the first kind. In order to elucidate this remark, which is of great importance in the present discussion, let A be the centre, and B C N the circumference of a wheel 6 feet in diameter, and let the impelling power P, which is attached to the extremity of a rope A D P, passing over the pulley D, act in the horizontal direction A D. Then, if the wheel is not affected by friction, it will be put in motion upon the level surface M B, when the power P is infinitely small. For since the whole weight of the wheel rests on the ground at the point B, which is the fulcrum of the lever A B, the distance of the weight from the centre of motion will be nothing, and therefore the mechanical energy of the smallest power P, acting at the point A, with a length of lever A B, will be infinitely great when compared with the resistance of the

weight to be raised; and this will be the case, however small the lever A B, and however great be the weight of the wheel. But as the wheels of carriages are constantly meeting with impediments, let C be an obstacle six inches high, which the wheel is to surmount. Then the spoke A C will represent the lever, C its fulcrum, A D the direction of the power; and if the wheel weighs 100 pounds, we may represent it by a weight W, fixed to the wheel's centre A, or to the extremity of the lever C A, and acting in the perpendicular direction A B, in opposition to the power P. Now the mechanical energy of the weight W to pull the lever round its fulcrum in the direction A E, is represented by C E, while the mechanical energy of an equal weight P to pull it in the opposite direction A F, is represented by C F; an equilibrium, therefore, will be produced, if the power P is to the weight W as C E to C F, or as the sine is to the cosine of an angle, whose versed sine is equal to the height of the obstacle to be surmounted; for E B, the height of the mound C, is the versed sine of the angle B A C, and C E is the sine, and C F the cosine of the same angle. In the present case, where E B is six inches, and A B three feet, E B, the versed sine, will be 1666, &c. when A B is 1000; and, consequently, the angle B A C will be $33^{\circ} 33'$, and C E will be to E F, as 52 to 83, or as 66 to 100. A weight P, therefore, of 66 pounds, acting in a horizontal direction, will balance a wheel six feet diameter, and 100 pounds in weight, upon an obstacle six inches high; and a small additional power will enable it to surmount that obstacle. But if the direction, A D, of the power, be inclined to the horizon, so that the point D may rise towards H, the line F C, which represents the mechanical energy of P, will gradually increase, till D A has reached the position H A, perpendicular to A C, where its mechanical energy, which is now a maximum, is represented by A C, the radius of the wheel; and since E C is to C A as 53 to 1000, a little more than 53 pounds will be sufficient for enabling the wheel to overcome the obstacle.

Proceeding in this way, it will be found, says our author, that the power of wheels to surmount eminences increases with their diameter, and is directly proportional to it, when their weight remains the same, and when the direction of the power is perpendicular to the lever which acts against the obstacle. Hence we see the great advantages which are to be derived from large wheels, and the disadvantages which attend small ones. There are some circumstances, however, which confine us within certain limits in the use of large wheels. When the radius A B of the wheel is greater than D M, the height of the pulley, or of that part of the horse to which the rope or pole D A is attached, the direction of the power, or the line of traction A D, will be oblique to the horizon as A d, and the mechanical energy of the power will be only A e, whereas it was represented by A E when the line of traction was in the horizontal line D A. Whenever the radius of the wheel, therefore, exceeds four feet and a half, the height of that part of the horse to which the traces should be attached, the line of traction A D will incline to the horizon, and by declining from the perpendicular A H, its mechanical effort will be diminished; and since the load rests upon an inclined plane, the trams or poles of the cart will rub against the flanks of the horse, even in level roads, and still more severely in descending ground. Notwithstanding this diminution of force, however, arising from the unavoidable obliquity of the impelling power, wheels exceeding four and a half feet radius have still the advantage of smaller ones; but their power to overcome resistances does not increase so fast as before. Hitherto we have supposed the weight of the large and small wheels to be the same, but

it is evident that when we augment their diameter we add greatly to their weight; and by thus increasing the load, we sensibly diminish their power.

From these remarks, we see the superiority of great wheels to small ones, and the particular circumstances which suggest the propriety of making the wheels of carriages less than four feet and a half radius. But even this size is too great; and it may be safely asserted that they should never exceed six feet in diameter, nor ever be less than three feet and a half.

6. Carriages with four wheels, as waggon or coaches, are much more advantageous than carriages with two wheels, as carts and chaises; for in applying horses to a carriage with two wheels, it is plain that the tiller carries part of the weight, in whatsoever manner it be kept in equilibrio upon the axle. In going down a hill, the weight bears upon the horse; and in going up a hill, the weight falls the other way, and lifts the horse, by which means part of his force is lost. Besides, as the wheels sink into the holes in the road, sometimes on one side, sometimes on the other, the shafts strike against the tiller's flanks, which is the destruction of many horses. Add to this, that when one of the wheels sinks into a hole or rut, half the weight will fall that way, whereby the carriage will be in danger of being overturned.

7. It would be much more advantageous to make the four wheels of a coach or waggon large, and nearly of a height, than to make the fore-wheels of only half the diameter of the hind-wheels, as is usual in many places. The fore-wheels of carriages have commonly been made of a less size than the hind ones, both on account of turning short, and to avoid cutting the braces. Crane-necks have also been invented for turning yet shorter, and the fore-wheels have been lowered, so as to go quite under the bend of the crane-neck. See an account of an ingenious contrivance for this purpose, under PERCH.

Some carriers and coachmen have, indeed, absurdly alleged, that when the fore-wheels are much lower than the hind ones, they serve to push them on. However, many disadvantages attend this construction. A considerable force is lost that would be effectual, if they were large: the carriage would go much more easily, if the fore-wheels were as high as the hind-ones; and the higher the better, because their motion would be so much the slower on their axles, and consequently the friction proportionably diminished. The jolting and uneasy motion occasioned by low wheels, has induced persons to contrive springs, in order to prevent it. But nothing can be more inconsistent, even with this end, than the common method of fixing the braces to the bottom of the body of a carriage. In consequence of this practice, the centre of gravity of the suspended body is so high above the centre of its motion, that it is liable to be continually agitated by the jolting of the carriage, and its danger of overturning increased: whereas if, instead of practising this method, the body were suspended as near as possible to its centre of gravity, the agitation of the carriage, as well as its danger of overturning, would be in a great measure avoided.

The effect of the suspension of a carriage on springs is to equalize its motion, by causing every change to be more gradually communicated to it, by means of the flexibility of the springs, and by consuming a certain portion of every sudden impulse in generating a degree of rotatory motion. This rotatory motion depends on the oblique position of the straps suspending the carriage, which prevents its swinging in a parallel direction; such a vibration as would take place if the straps were parallel, would be too extensive, unless they were very short, and then the motion would be some-

what rougher. The obliquity of the straps tends also in some measure to retain the carriage in a horizontal position: for if they were parallel, both being vertical, the lower one would have to support the greater portion of the weight, at least according to the common mode of fixing them to the bottom of the carriage; the spring, therefore, being flexible, it would be still further depressed. But when the straps are oblique, the upper one assumes always the more vertical position, and consequently bears more of the load; for when a body of any kind is supported by two oblique forces, their horizontal thrusts must be equal, otherwise the body would move laterally; and in order that the horizontal portions of the forces may be equal, the more inclined to the horizon must be the greater: the upper spring will, therefore, be a little depressed, and the carriage will remain more nearly horizontal than if the springs were parallel. The reason for dividing the springs into separate plates has already been explained: the beam of the carriage, that unites the wheels, supplies the strength necessary for forming the communication between the axles: if the body of the carriage itself were to perform this office, the springs would require to be so strong that they could have little or no effect in equalizing the motion, and we should have a waggon instead of a coach. The ease with which a carriage moves, depends not only on the elasticity of the springs, but also on the small degree of stability of the equilibrium, of which we may judge in some measure, by tracing the path which the centre of gravity must describe, when the carriage swings.

There is an inconvenience which attends the usual method of loading carriages; for when a carriage is loaded equally heavy on both axles, the fore-axle must endure as much more friction, and consequently wear out as much sooner than the hind-axle, as the fore-wheels are less than the hind ones. However, the carriers commonly put the heavier part of the load upon the fore-axle of the waggons; which not only makes the friction greatest where it ought to be least, but also presses the fore-wheels deeper into the ground than the hind-wheels, although the fore-wheels, being less than the hind ones, are with so much the greater difficulty drawn out of a hole, or over an obstacle, even supposing the weights on their axles were equal; for the difficulty, with equal weights, will be as the depth of the hole, or height of the obstacle, is to the semi-diameter of the wheel. Moreover, since a small wheel will often sink to the bottom of a hole, in which a great wheel will go but a very little way, the small wheels ought to be loaded with less weight than the great ones; and then the heavier part of the load would be less jolted upward and downward, and the horses tired so much the less, as their draught raised their load to less heights. When the waggon-road, indeed, is much up-hill, there may be danger in loading the hind-part much heavier than the fore-part; for then the weight would overhang the hind axle, especially if the load be high, and endanger tilting up the fore-wheels from the ground. In this case, the safest way would be to load it equally heavy on both axles; and then as much more of the weight would be thrown upon the hind axle than upon the fore one, as the ground rises from a level below the carriage. But as this seldom happens, a small temporary weight might be laid upon the pole between the horses, which would overbalance the danger.

From Mr. Ferguson's observations on the centre of gravity, it is evident, that if the axle-tree of a two-wheeled carriage passes through the centre of gravity of the load, the carriage will be in equilibrio in every position in which it can be placed with respect to the axle-tree; and

in going up and down hill, the whole load will be sustained by the wheels, and will have no tendency either to press the horse to the ground, or to raise him from it. But if the centre of gravity is far above the axle-tree, as it must necessarily be according to the present construction of wheel-carriages, a great part of the load will be thrown on the back of the horses from the wheels, when going down a steep road, and thus tend to accelerate the motion of the carriage, which the animal is striving to prevent: while in ascending steep roads a part of the load will be thrown behind the wheels, and tend to raise the horse from the ground, when there is the greatest necessity for some weight on his back, to enable him to fix his feet on the earth, and overcome the great resistance which is occasioned by the steepness of the road. On the contrary, if the centre of gravity is below the axle, the horse will be pressed to the ground in going up-hill, and lifted from it when going down. In all these cases, therefore, where the centre of gravity is either in the axle-tree, or directly above or below it, the horse will bear no part of the load in level ground. In some situations, the animal will be lifted from the ground when there is the greatest necessity for his being pressed to it, and he will sometimes bear a great proportion of the load when he should rather be relieved from it.

The only way of remedying these evils, says Dr. Brewster, is to assign such a position to the centre of gravity, that the horse may bear some portion of the load when he must exert great force against it, that is, in level ground, and when he is ascending steep roads; for no animal can pull with its greatest effort, unless it is pressed to the ground. Now, this may in some measure be effected in the following manner:—Let *BCN* (*Plate XL. fig. 12.*) be the wheel of a cart, *A* D one of the shafts, *D* that part of it where the cart is suspended on the back of the horse, and *A* the axle-tree; then if the centre of gravity of the load is placed at *m*, a point equidistant from the two wheels, but below the line *DA*, and before the axle-tree, the horse will bear a certain weight on level ground, a greater weight when he is going up-hill, and has more occasion for it, and a less weight when he is going down-hill, and does not require to be pressed to the ground. All this will be evident from the figure, when we recollect that if the shaft *DA* is horizontal, the centre of gravity will press more upon the point of suspension *D* the nearer it comes to it; or the pressure upon *D*, or the horse's back, will be proportional to the distance of the centre of gravity from *A*. If *m* therefore be the centre of gravity, *bA* will represent its pressure upon *D*, when the shaft *DA* is horizontal. When the cart is ascending a steep road, *AH* will be the position of the shaft, the centre of gravity will be raised to *a*, and *aA* will be the pressure upon *D*. But if the cart is going down hill, *AC* will be the position of the shaft, the centre of gravity will be depressed to *n*, and *cA* will represent the pressure upon the horse's back. The weight sustained by the horse, therefore, is properly regulated by placing the centre of gravity at *m*. We have still, however, to determine the proper length of *ba* and *bm*, the distance of the centre of gravity from the axle, and from the horizontal line *DA*; but as these depend upon the nature and inclination of the roads, upon the length of the shaft *DA*, which varies with the size of the horse, on the magnitude of the load, and on other variable circumstances, it would be impossible to fix their value. If the load, along with the cart, weighs four hundred pounds, if the distance *DA* be eight feet, and if the horse should bear fifty pounds of the weight, then *bA* ought to be one foot, which being one-eighth of *DA*, will make the pressure upon *D* exactly fifty pounds. If the road slopes four inches in one foot,

b m must be four inches, or the angle *b A m* should be equal to the inclination of the road, for then the point *m* will rise to *a* when ascending such a road, and will press with its greatest force on the back of the horse.

When carts are not constructed in this manner, we may, in some degree, obtain the same end by judiciously disposing the load. Let us suppose that the centre of gravity is at *O* when the cart is loaded with homogeneous materials, such as sand, lime, &c. then if the load is to consist of heterogeneous substances, or bodies of different weight, we should place the heaviest at the bottom, and nearest the front, which will not only lower the point *O*, but will bring it forward, and nearer the proper position *m*. Part of the load, too, might be suspended below the fore-part of the carriage in dry weather, and the centre of gravity would approach still nearer the point *m*. When the point *m* is thus depressed, the weight on the horse is not only judiciously regulated, but the cart will be prevented from overturning, and in rugged roads the weight sustained by each wheel will be in a great degree equalized.

In loading four-wheeled carriages, great care should be taken not to throw much of the load upon the fore-wheels, as they would otherwise be forced deep into the ground, and require great force to pull them forward. In some modern carriages, this is very little attended to. The coachman's seat is sometimes enlarged so as to hold two persons, and all the baggage is generally placed in the front, directly above the wheels. By this means the greatest part of the load is upon the small wheels, and the draught becomes doubly severe for the poor animals, who must thus unnecessarily suffer for the ignorance and folly of man.

There is another great disadvantage attending small fore-wheels; viz. that as their axle is below the level of the horse's breasts, the horses not only have the loaded carriage to draw along, but also part of its weight to bear, which tires them sooner, and makes them grow much stiffer in their hams, than they would be if they drew on a level with the fore-axle; and for this reason, coach-horses soon become unfit for riding. So that on all accounts it is plain, that the fore-wheels of all carriages ought to be so high as to have their axles even with the breasts of the horses; which would not only give them a fair draught, but likewise cause the machine to be drawn by a less degree of power.

Mr. Beighton disputes the propriety of fixing the line of traction on a level with the breast of a horse, and says it is contrary to reason and experience. Horses, he says, have little or no power to draw, but what they have from their weight; otherwise they could take no hold of the ground, and then they must slip, and draw nothing. Common experience also teaches, that if a horse is to convey a certain weight, he ought, that he may draw the better, to have a proportional weight on his back or shoulders. Besides, when a horse draws hard, he bends forward, and brings his breast near the ground; and then, if the wheels are high, he is pulling the carriage against the ground. A horse tackled in a waggon will draw two or three ton, because the point or line of traction is below his breast, by reason of the wheels being low. And it is very common to see, when one horse is drawing a heavy load, his fore-feet will rise from the ground; and he will nearly stand on end; in which case it is usual to add a weight on his back, to keep his fore-part down, by a person mounting on him, which will enable him to draw that load, without which he before could not move. The great stress, or main business of drawing, says this ingenious writer, is to overcome obstacles; for on level plains the drawing is but little, and then the horse's back need be pressed but with a small weight. Most or all of these obstacles may be

considered as inclined planes. In order to draw the wheel *A B* (*Plate XL. Mechanics, fig. 13.*) over the obstacle *D*, *M. de Camus*, agreeably to the principles above laid down, would have the horse draw in the line *H C*; whereas *Mr. Beighton* says, since the obstacle is *D*, and the tangent of the earth, or line of the floor, is at *B*, and the line to be moved in is *B D*, an inclined plane; the easiest position of drawing, to get the wheel over *D*, is to draw in the position of that inclined plane *B T*, or its parallel *C b*. As all the radii of a wheel are equal, the pulling at the centre is the same as a balance in equilibrio; viz. there is the same force at *A* as at *B*. But in the case of drawing in the horizontal line *H C*, when the obstacle is at *D*, the whole force which the horse has for drawing is by the short end of the brachium $= e D$, against the force or weight of the long end of the brachium $f D = e C$, which must be very disadvantageous; therefore, he says, the line of traction should be *b C*. *Defag. Exp. Phil. vol. ii. App. p. 542, &c.*

Whilst *M. Camus* maintained that the line of traction should be an horizontal line, or always parallel to the ground on which the carriage is moving, because the horse can exert his greatest strength in this direction, and because the line of draught, being perpendicular to the vertical spoke of the wheel, acts with the largest possible lever, *M. Couplet*, considering that the roads are never perfectly level, and that the wheels are constantly surmounting small eminences, even in the best roads, recommends the line of traction to be oblique to the horizon. It is, however, to *M. Deparcieux* (*Sur le Tirage des Chevaux, Mem. Acad. Roy., 1760.*), that we are principally indebted for just ideas on this subject. He has shewn in the most satisfactory manner that animals draw by their weight, and not by the force of their muscles. In four-footed animals, the hinder feet are the fulcrum of the lever by which their weight acts against the load; and when the animal pulls hard, it depresses its chest, and thus increases the lever of its weight, and diminishes the lever by which the load resists its effects. Thus in *Plate XL. Mechanics, fig. 12*, let *P* be the load, *D A* the line of traction, and let us suppose *F C* to be the hinder leg of the horse, *A F* part of its body, *A* its chest or centre of gravity, and *C E* the level road. Then *A F C* will represent the crooked lever by which the horse acts, which is equivalent to the straight one *A C*. But when the horse's weight acts downwards at *A*, round *C* as a centre, so as to drag forward the rope *A D*, and raise the load *P*, *C E* will represent the power of the lever in this position, or the lever of the horse's weight, and *C F* the lever by which it is resisted by the load, or the lever of resistance. Now, if the horse lowers its centre of gravity *A*, which it always does when it pulls hard, it is evident that *C E*, the lever of its weight, will be increased, while *C F*, the lever of its resistance, will be diminished, for the line of traction *A D* will approach nearer to *C E*. Hence we may see the great benefit which may be derived from large horses, for the lever *A C* necessarily increases with their size, and their power is always proportioned to the length of this lever, their weight remaining the same. Large horses, therefore, and other animals, will draw more than small ones, even though they have less muscular force, and are unable to carry such a heavy burden. The force of the muscles tends only to make the horse carry continually forward his centre of gravity; or, in other words, the weight of the animal produces the draught, and the play and force of its muscles serve to continue it.

From these remarks, then, according to *Dr. Brewster's* statement, we may deduce the proper position of the

line of traction. When the line of traction is horizontal, as *A D*, the lever of resistance is *C F*; but if this line is oblique to the horizon, as *A d*, the lever of resistance is diminished to *C f*, while the lever of the horse's weight remains the same. Hence it appears, that inclined traces are much more advantageous than horizontal ones, as they uniformly diminish the resistance to be overcome. *Deparcieux*, however, has investigated experimentally the most favourable angle of inclination, and found, that when the angle *D A F*, made by the trace *A d*, and a horizontal line, is fourteen or fifteen degrees, the horses pulled with the greatest facility and force. This value of the angle of draught will require the height of the spring-tree bar, to which the traces are attached in four-wheeled carriages, to be one-half of the height of that part of the horse's breast to that with which the fore end of the traces is connected.

This height is about four feet six inches, and therefore the height of the spring-tree bar should be only two feet three inches, whereas it is generally three feet.

8. The utility of broad wheels, in amending and preserving the roads, has been so long and generally acknowledged, as to have occasioned several acts of the legislature to enforce their use. See *TURNPIKE*.

Several excellent and well-devised experiments have not long ago been instituted by *Boulard* and *Margueron*, which have satisfactorily evinced the distinguishing advantage of broad wheels. See a Memoir presented to the Academy of Lyons, in the *Journal de Physique*, tom. xix. p. 424.

Nevertheless, the proprietors and drivers of carriages seem to be convinced by experience, that a narrow-wheeled carriage is more easily and speedily drawn by the same number of horses than a broad-wheeled one of the same burthen. And though government allowed them to draw with more horses, and carry greater loads than usual, they were persuaded with difficulty to comply with the requisition of legislature; and methods have been used to evade it. Their principal objection has been, that as a broad wheel must touch the ground in many more points than a narrow wheel, the friction must of course be so much the greater; not considering, that if the whole weight of the waggon, and load in it, bears upon many points, each sustains a proportionable less degree of weight and friction than when it bears only upon a few points; so that what is wanting in one is made up in the other, and, therefore, will be just equal under equal degrees of weight, as appears by the following plain and easy experiment proposed by *Mr. Ferguson*.

Let one end of a piece of packthread be fastened to a brick, and the other end to a common scale for holding weights; then having laid the brick edgewise on a table, and letting the scale hang under the edge of the table, put as much weight into the scale as will just draw the brick along the table. Then taking the brick to its former place, lay it flat on the table, and leave it to be acted upon by the same weight in the scale as before, which will draw it along with the same ease as when it lay upon its edge. In the former case, the brick may be considered as a narrow wheel on the ground; and in the latter as a broad wheel. And since the brick is drawn along with equal ease, whether its broad side or narrow edge touches the table, it shews that a broad wheel might be drawn along the ground with the same ease as a narrow one, supposing them equally heavy, even though they should drag, and not roll as they go along. Besides, as narrow wheels are always sinking into the ground, especially when the heaviest part of the load lies upon them, they must be considered as constantly going up hill, even on level ground; and their edges must sustain much friction by

rubbing against the sides of the ruts made by them. But both these inconveniences are avoided by broad wheels; which, instead of cutting and ploughing up the roads, roll them smooth, and harden them: though, after all, it must be confessed, that they will not do in stiff, clayey cross roads; because they would soon gather up as much clay as would be almost equal to the weight of an ordinary load; and also in passing along roads abounding with loose stones and other obstacles, which a narrow wheel may avoid passing over, and a broad one must surmount, the broad-wheel carriage will certainly be drawn less easily and less speedily than a narrow-wheeled one, though not on account of any additional friction arising from the pressure of the weight on a greater quantity of surface. Broad wheels are likewise more liable to an inequality of pressure between the axle and box than narrow ones, and consequently to a greater wear and tear.

Jacob's Obs. on the Structure and Draught of Wheel-Carriages, 1773, p. 81, &c. See on the subject of the preceding article, Defag. Ex. Phil. vol. i. p. 201, &c. Ferguson's Lect. p. 56, &c. 4to., and Appendix by Brewster. Martin's Phil. Brit. vol. i. p. 229, &c.

We shall here subjoin some additional remarks on wheels and axles for carriages. The essential qualities of wheels are strength and durability, and it is desirable that they should be as light as is consistent with strength: for quick travelling carriages lightness is very necessary.

Wheels to four-wheel carriages should be made as near of a height as the construction and appearance will admit; and if not required for heavy work, the lighter they are made the better. The fixtures from whence the draught is taken should be placed rather above the centre of the largest wheel, for advantage of draught.

The members of a wheel are of three descriptions; viz. the nave, or stock, which is the central piece; the spokes, or radii; and the fellyes, or circumference. The nave or stock is made of elm, in which all the spokes are fixed, and in which the axletree-box, or wheel-box, is confined, to receive the axle-arms on which the wheel revolves. The spokes are straight timbers made of oak, firmly tenoned in the nave, in the direction of radials, to support the fellyes, or wheel-rim. The fellyes are made of ash, or beech, and form the rim of the wheel; the whole circumference is usually divided into short lengths, in the proportion of one length to every two spokes. When the fellyes are fixed on the spokes, the iron band, or tire, which maintains the wear, is nailed on in lengths, and keeps the fellyes together. The diameters of wheels regulate the number of spokes and fellyes they are to contain: for the larger the circumference of the wheel is, the greater is the number of spokes required in proportion; for they should not in any wheel be more than fifteen inches distant on the fellyes, or circumference.

The usual height or diameter of wheels for coaches and travelling carriages extends to five feet eight inches, and are divided into four proportions. Those which contain from eight to fourteen spokes, and only half that number of fellyes, are called eights, tens, twelves, or fourteens, which are the number of spokes in such wheels, or of fellyes in a pair of wheels. The height which regulates the number is, for an eight-spoke wheel, not to exceed three feet two inches; for a ten, four feet six inches; for a twelve, five feet four inches; for a fourteen, five feet eight inches.

These are the extreme heights for the different numbers of spokes to each wheel, which should be rather more than less, in particular for the fore-wheel of a four-wheel carriage, which receives more stress than the hind one; and the coach-maker's rule is, when the hind-wheels are of that height to

require fourteen spokes, the fore one, if under the necessary height before stated, should have twelve; never allowing the fore-wheels to have but two spokes less than what is needful for the hind ones.

There are three descriptions of wheels; viz. the straked, the hooped, and the patent rim: the differences of these are only in the rims.

The straked wheel is made with the fellyes in separate lengths or pieces, which are joined together at the ends by dowels; that is, a round pin which enters part into one piece and part into the other, being closely fitted into holes made in each. The iron with which it is plated is called the strake, and is put on in pieces of the same length as the pieces of the fellyes, and fastened by nails; the joints of the iron are made to fall over the middle of the pieces of wood so as to unite them firmly together. The hooped wheel is surrounded by a hoop of iron in one entire piece. The patent wheel is made with a hoop of wood in one entire piece, by boiling or softening the wood until it can be bent into a circle; this is surrounded by a hoop of iron in an entire piece, and fastened by nuts and rivets.

According to the usual method of constructing straked wheels, their peripheries are composed of a number of pieces or fellyes joined together; but these are weak, and subject to several inconveniences. As the joints are the weakest parts of the wheel, they are most liable to yield inward; for which reason the wheelwrights leave them higher than the other parts of the rim, in consequence of which the wheel is not exactly round within the circle of the rim. Besides, the fellyes being segments of a circle, sawed or hewn out of straight wood, they are on this account rendered so brittle, from the cross direction of the grain near the joints, that they are with difficulty kept together, even though almost twice the quantity of timber be employed that would otherwise be necessary. The strength of such a wheel depends on the thickness of the iron tire or rim that surrounds it, and hence the carriage is loaded with an useless weight, both of wood and iron. To obviate these inconveniences, Mr. Viny invented the process for bending timber into a circular form, practised for some time by Messrs. Jacob and Viny, and is now continued by others. In wheels made of timber thus bent, the rim consists either of a single piece of wood, or two fellyes only, and is cased with a single hoop of iron. By this mode of construction, the grain of the wood is kept parallel throughout, so that the periphery of the wheel is every where equally strong; its thickness is considerably lessened, inasmuch that though little more than half the usual quantity of timber is employed, the wheel is of itself strong enough to sustain the common burthen laid on such wheels, without the assistance of iron tires, which are only applied to them as a safe-guard, to preserve the wood from the injuries to which it would otherwise be necessarily exposed from the roads; and hence a less quantity of iron is sufficient, and even that will be fairly worn out before it becomes useless. Besides, the wheel is rendered much lighter, and at the same time much stronger and more durable, than wheels constructed of detached pieces of wood and iron, in the usual manner. These patent wheels are very superior to the common sort, in their neat light appearance, and in the length of time they wear, as two sets of the former will wear as long as three of the latter: their preservation depends very much on the hoops that the wheels are rimmed with. Some persons still prefer the common sort of wheels, on account of their being more easily repaired than the hoop-wheel; but though the repairing of the latter is more difficult, they are much less subject to need it.

As the rims of wheels wear soonest at their edges, they

should be made thinner in the middle, and fattened to the felloes with nails of such a kind, that their heads may not rise above the surface of the rim. The felloes on which the rims are fixed should, in carriages, be three inches and a quarter deep, and in waggon four inches. The naves should be thickest at the place where the spokes are inserted, and the holes in which the spokes are placed should not be bored quite through, as the grease upon the axle-tree would insinuate itself between the spoke and the nave, and prevent that close adhesion which is necessary to the strength of the wheel.

The track in which the wheels of every carriage are to run is generally the same, except when intended for particular roads, where waggon and other heavy carriages are principally used, and leave very deep ruts, in which light carriages must likewise run, or be liable to accident, and are also sure to be heavy in draught. All four-wheel carriages should have the hind and fore wheels regulated to roll in the same track. The ordinary width of the wheels is four feet eight or ten inches; that of waggon or carts generally measure five feet two inches; chaise-wheels, as being principally intended for the country, are adapted to this width. It is immaterial to what width wheels are set if used for running upon stones; but on marshy roads, if their exactness is not attended to, the draught is considerably increased. We have seen a carriage of which the iron axle-tree is made in two pieces, overlapping each other in the middle where they are joined, and secured by proper bands to the wood-work of the carriage, so as to admit of sliding in the direction of the axle-tree. These parts are cut with teeth like racks, and a pinion is applied between them; so that by turning this pinion round, the two parts of the axle-tree are made to slide one upon the other; and the wheels which are fitted upon the two extreme ends of the axle-tree can at pleasure be fixed at greater or less distance, as the roads require.

The different heights of hind and fore wheels make also a difference in the length of their axle-trees, agreeable to the proportion they bear to one another; the fore-wheel has the longest axle-tree by one or two inches between the shoulders.

The nave of the wheel is pierced through the centre, with a large hole to introduce the box, or iron tube, for the axle-arm, as this tends to weaken the wood. It has been frequently proposed to make metal naves, or centre-pieces for wheels, which should contain the box for the axis, and the mortises for the spokes of the wheel all cast of one piece of metal. Messrs. Dodson and Skidmore had a patent for this in 1799. The objection to it is, that, if the wood of the spokes shrinks, they become loose in the mortises, whereas a wooden nave shrinks at the same time with the spoke. This defect has been since remedied by making the metal wheel-stock in two parts; one with recesses, or sockets, to contain the spokes, and the other a flat plate to fasten against the former with screw-bolts, and press the spokes into their cavities. Mr. Plucknet had a patent for a metal wheel-stock of this kind in 1805, which answered extremely well for carts, waggon, and artillery. The spokes were made to fill up all the space in the nave or stock, so that each spoke touched its neighbour. The metal stock was only a flat circular plate, or flanch, projecting from the box which received the axle, and another flat plate fitted upon it, and bound against the former by screw-bolts, one passing through each arm; these rendered the wheel very strong.

Mr. Wilks took a patent in 1813 for a metal stock, in which there are complete cells for each spoke, and the cells are dove-tailed; that is, they are made larger at the central part than at the outside, to prevent them from drawing out, and

they are firmly pressed into the dove-tails by the screw-bolts which confine the moveable plate.

Wheels for railway-waggon are made of cast-iron, and usually all in one piece; but this is objectionable, because the unequal contraction of the arms and rim of the wheel in cooling, after the wheel is cast, puts the different parts on a strain, and they frequently break without any adequate force. It is better to cast the rim in one piece and the arms in another, and put them together with screw-bolts, or rivets. Mr. Hawks had a patent for this in 1807. In this way, the rims may be replaced when worn out.

The Axle-trees for Wheels of Carriages.—The strong iron bar which extends across beneath the wood-work of the carriage, is called the axle-tree; the round parts at each end, on which the wheels run, are called the axle-arms; and the part or stem between them, which is fixed beneath the wood-work of the carriage, is also called the axle-tree. In the form of the latter parts there are but two sorts, the one made flat, and called a bedded axle-tree, it being sunk all its length in the under side of the timbers of the carriage; the other is made of an octagon form, and flat only at the ends where they are bedded.

The axle-arms on which the wheels turn should be made perfectly round, and somewhat stronger at the shoulder than at the extreme end, which is screwed to receive a nut, through which and the axle-tree the lynch-pin passes, to keep all tight. The nuts are made with a collar at the face; and a temporary collar, or washer, is driven on the back of the arms, which form two shoulders for the wheel to wear against, and helps to preserve the grease from running out, and to prevent dirt from getting in.

As the axle-trees are the principal or only support of the carriage, every attention and care should be fixed in the selection of good iron; and to see that they be well wrought, and of sufficient strength, rather going to the extreme of strength, than risking the life of the passenger by the over-setting of the carriage, which mostly happens when an axle-tree breaks.

By the bend of the axle-trees, the wheels are regulated to any width at bottom, to suit the track of the roads in which they are to run, and are confined in the carriage by means of clips, hoops, and bolts. The shape of the axle-tree between the shoulders varies according to the situation they are placed in, or the form of the timber of the carriage with which they are united; those are the most firm that are flat, bedded in the timber. Axle-tree boxes for wheels are of various kinds; those which are frequently called long-pipe, or wheel-boxes, are long tubes fitted accurately to the arms of the axle-trees, and securely fixed in the wheel-stocks, or naves; they are usually made of wrought sheet-iron of a substance proportioned to the weight of the carriage; their use is to contain a supply of grease, and to prevent the effects of friction, whereby the wheels are much assisted in their motion. These are now used instead of the old cast-iron boxes, which for quick travelling-carriages are totally out of use, being found injurious to the axle-trees, by cutting them at those parts they wear against, so as to occasion a frequent lining of the arms; but with the wrought metal boxes this is seldom necessary.

There are many sorts of axle-trees and boxes invented various ways, with a view of attaining the following advantages; viz. To contain a longer supply of grease or oil, to be more durable, to secure the wheels, and to lessen the draught. Those are all certainly great advantages, and though the expence is great, the utility of either of them must be more than adequate to it, and merits more general notice.

Some of these inventors even pretend that all these advantages are combined in one axle-tree; but the generality extend to the advantage only of retaining a supply of oil, and remaining perfect to a considerable length of time. The common sort of axle-tree and box, which is most generally used, is simple and cheap in comparison with the others.

Common Axle-tree.—The arms of the axle-tree are made round, but rather of a conical form, strongest at the back or shoulders, tapering to the lynch end, which is screwed for a nut, and also has a small hole for a lynch-pin, which prevents the nut from coming off: at the body-end is a washer or collar for the back of the wheel-stock to wear against. The box is made of sheet-iron, proportioned in substance to the weight or size of the axle-tree, having the edges of the plate, of which it is formed, welded in a ridge which projects on the outside; this secures the box in the nave of the wheel, and prevents it turning round therein.

The nut which screws on the end of the axle-arm has a broad face to lie flat against the wheel, and is tapped or screwed to receive the screw-end of the axle-tree. Each of those nuts must turn on the screw the same way the wheel goes, and must have a notch for the lynch-pin to pass through, for the purpose of securing the nut from turning off.

The box is what, of the axle-tree, wears most, and is frequently obliged to be refitted to the arms; otherwise they give to the wheel while in use an unsteady motion, and soon exhaust their stock of grease.

Those that are well fitted will contain their supply for about one week with regular use, or a journey of one hundred miles. They wear at the rate of one set of boxes to every two sets of wheels, and require in that time to be twice or thrice taken out of the wheels and refitted to the axle-tree arms.

Axle-trees with Friction-Wheels.—These were invented by Mr. Garnet, at least the best kind, which are made in a very ingenious manner. The wheel-box is made much larger than the axle-tree, in such manner that the space all round between them may receive a number of rollers which fill it up. (See a description in the article *MILL-Work*.) Mr. Garnet had a patent in 1784, and for some years manufactured great numbers; but being very expensive, they fell into disuse, although very complete. This invention has been lately revived by Mr. Panter.

The Patent Anti-Affriction Axle-tree and Box.—The proposed advantages of this axle-tree are, ease of draft by diminution of friction; the retention of oil to supply a month's use; the ease with which it is replenished without taking off the wheels; the great security for the wheels, which it prevents from coming off, and the carriage from overturning, if even the arm of the axle-tree should break; and their durability, and even improvement by wear. Those axle-trees, if made with the securing-collar, for the wheels need no nut or lynch-pin, as is generally used, but the wheel may be taken off and put on as easily as those on the common principle.

These axle-arms are reduced at the bottom from a perfect round, and grooved, to receive two small rollers, on which the weight of the carriage is borne, and which greatly facilitates the motion, in the same manner as blocks of stone or timber, which require to be removed by the assistance of rollers. These rollers form the outer circumference of the axle-trees at bottom, which are reduced to give a bearing only on them. A circular box or cistern is provided to contain a supply of oil; it is closely fitted to the back of the inner end of the wheel-stock, and fixed by three bolts. The oil is here contained within three circular recesses, and

oozes through small channels on the arm of the axle-tree, which it feeds for a considerable time. This oil-box is made of cast-metal, and has a cap projecting behind over the axle-tree, which prevents the dirt from getting into the box. This axle-tree is also provided with what is called the wheel-security, or strap-washer. It is an iron collar, fitted on the external part of the wheel-stock, and confined between the reservoir and stock, lying as it were in a groove, so that the collar cannot come off. This collar has two lugs or straps extending backwards some distance along that part of the axle-tree which is bedded in the wood-work, where it is fixed by a nut-screw. By means of this strap-washer, the wheel is secured to the bedded part of the axle-tree; and should the axle-arm within the wheel break, the wheel will continue to act.

The cap of this axle-tree is also fixed on the outside part of the wheel-stocks; by the same three bolts which fasten the oil-box, and by means of a screw-plug in the cap, the axle-tree and reservoir are replenished with oil. The box is of the same form as the common box, only made of a very hard durable metal, of a considerable thickness, and is made in proportion to the weight of the carriage.

Collinge's Patent Cylinder Axle-tree and Box.—These axle-trees have been a considerable time in use, and their advantages have been proved in the length of time they wear, in the silent and steady motion they preserve to the wheels, in the advantage of retaining the oil to prosecute a journey of two thousand miles without being once replenished; and lastly, they are very durable, and but little subject to be out of order.

The axle-tree arm is made as perfectly cylindrical as possible, and of a peculiar hard substance; the middle of the cylinder is reduced, to contain the oil necessary to feed the axle-trees; so that the two bearings are at the two ends of the axle, which has an internal shoulder, against which the inner end of the wheel-box takes its bearings. Behind this shoulder is a deep groove for a washer to preserve the oil, and prevent noise in its use; also a rim, or hollow box, on the collar of the axle-tree, which overlaps part of the inner end of the wheel-stock to keep out dirt, and answer the use of a cuttoo. The extreme end of the arm is double-screwed, to receive two nuts for securing the wheel: the one screw turns the way of the wheel; the other the reverse, and is meant as an additional security.

The box is made of a very hard metal, nicely polished, and fitted to the arms, having a circular recess all round at the end nearest the carriage, for containing there a supply of oil. The box is longer than the part which bears on the axle; and the projecting part beyond the bearing at each end is bored out larger than the arm. The back projection fits close to the rim of the collar, which it covers: the fore one projects outwards beyond the surface of the wheel-stock, and is screwed on the inside to receive the screw of the cap.

There are many other patents for axle-trees to wheels; but as few of them have come into use, we shall only notice Messrs. Flight and Brook's patent axles. The axle is fixed fast to the nave of the wheel, by passing through it. This axle turns round within the wheel-box; whereas in others the wheel-box turns round upon the axle.

The axle is cylindrical, and is received into a cylindrical box or tube in the end of the iron axle-tree, which is firmly bolted to the under side of the timber of the carriage. To hold the axle in its place, and prevent it from drawing out of the box, the end of the axle is reduced to a knob or button, which adheres to the end of the axle by a small

neck. This button is fitted and received into a socket, in which it can freely turn round, but cannot draw out endways. It is made in a piece of metal, which is cylindrical on the outside, and of the same size as the axle. It is made in two halves, which separate longitudinally to introduce or take out the button at the end of the axle; but when the two halves are put together, the socket-piece forms as it were a continuation of the axle. When the axle is put into the box with this socket-piece at the end of it, the two halves of the socket will be confined together, so that they cannot separate; and to prevent them from drawing out of the box, a screw-bolt is put through the box, and passes through both halves of the socket: this holds the socket and the axle in their places.

Mr. Ackermann has recently obtained a patent (1818) for a valuable improvement in the application of the fore-wheels to four-wheeled carriages. In our article *COACH-MAKING*, vol. viii. we have described those methods which were then known of applying the fore-wheels, so as to make a four-wheel carriage turn with safety, and in a small space. See also *PERCH*.

Mr. Ackermann's improvement effects this in the most perfect manner. Each of the fore axle-trees is connected with the carriage by means of a vertical axle, formed in the same piece with the horizontal axle, and upon which the wheel turns, the two axles being situated at right angles to each other. These vertical axles are fitted into sockets, formed at the two extremities of a cross beam of the frame of the carriage, which is called the fore-spring transom. Upon these axles, as centres of motion, the axle-arms and wheels can be turned about horizontally, in order to place them obliquely to the direction of the hinder-wheels when the carriage is required to turn; but each axle turns upon a separate centre of motion, and these centres are very near to their respective wheels, being at the extremities of the cross-beam or transom; hence the fore-wheels do not change their place upon the ground when they are placed obliquely.

In a common carriage, the axles of the two fore-wheels are both fixed to one piece of timber, called the axle-bed, which is placed beneath the fore-transom, and united to it by a vertical pin called the perch-bolt, passing through the middle of the axle-bed. On this pin, as a centre, the axle-bed is turned round. When the wheels are to be placed obliquely, it is evident, that, in so turning upon a single centre, one wheel must advance forwards, and the other must retreat backwards, so as to diminish the bearing of the carriage-wheels on the ground in a lateral direction, and at the same time the horses are pulling in that direction which tends to overturn the carriage. Another inconvenience is, that one of the wheels will touch the perch of the carriage, if placed very oblique.

In the new improvement, two separate centres of motion being used, and these being removed from each other as far as possible, many desirable properties are attained.

To give the oblique direction to the wheels, each vertical axle has a lever proceeding backwards from it; and these two levers are united together by a connecting-bar, which obliges both axles to move at the same time with a sympathetic action. The pole of the carriage is united to the piece, called the futchel, in the usual manner; and the futchel is united to the spring-transom by a perch-bolt, in the usual position; also the hinder end of the futchel is jointed to the middle of the connecting-bar, between the two levers of the vertical axles. The connecting-bar likewise answers the purpose of a sway-bar.

When the horses move to one side, the pole and futchel

turn upon the perch-bolt, as a lever upon a centre of motion; and the extreme end of the futchel acts upon both vertical axles at once by means of the connecting-bar, so as to place both of the fore-wheels in an oblique direction. This is the invention of M. Lankensperger of Munich.

WHEEL, *Aristotle's*. See *ROTA Aristotelica*.

WHEEL, *Blowing*, a machine contrived by Dr. Defaguiers for drawing out the foul air of any place, or for forcing in fresh, or doing both successively, without opening doors or windows. See *Phil. Transf.* N° 437.

The intention of this machine is the same as that of Dr. Hales's ventilator, but not so effectual, nor so convenient. See *Defagul. Course of Exper. Philos.* vol. ii. p. 563. 568.

This wheel is also called a *centrifugal wheel*, because it drives the air with a centrifugal force.

WHEELS, *Bushes or Boxes of*, the inside metal linings of the naves. See *WHEEL*.

WHEEL, *Cutting Roller*, in *Agriculture*, a tool of the cutting and reducing sort, used for the purpose of working over crops in some cases. In Oxfordshire a cutting roller of this sort has been invented, which is composed of twelve wheels, two inches and a half in thickness; and between each of them is a space of two inches and a half. They are three feet in diameter. It is a load in working so as to be sufficient exertion for a strong team to draw it: it is passed over wheat after it has been sown, or after it is come up; and if dry, crops and crops. It has also been used in the spring upon wheat; it leaves the surface rough in a sort of diamond forms, which is found very beneficial in some of the wheat-lands of that district. It is also capable of being used in breaking down the surface of stiff tillage-land in many other cases and circumstances.

WHEEL, *Draining*, a wheel constructed for the purpose of cutting or making drains. Wheels differently formed are used for this sort of work. In Essex they employ workmen who make use of a cast-iron wheel which weighs about four hundred weight, and which is four feet in diameter; the cutting edge or extreme circumference of the wheel being half an inch in thickness, which increases in this way as it approaches towards the nave or centre; and will, at fifteen inches deep, scour out or cut a drain half an inch wide at the bottom, and four inches wide at the top. The wheel is so placed in a frame, that it may be loaded at pleasure, and be made to pass to a greater or less depth, as the nature of the land may be.

The writer of the Middlesex Report on Agriculture advises the use of a common six-inch cart-wheel, on the felly of which, all round, a sort of ridge-formed addition of wood is to be fixed, and a rim of iron of a triangular shape fastened to the wood. A wheel of this kind put on the axle of a cart, in the usual way, will, of course, rest on the edge of the rim of iron; and which, on driving the horse forward, will make a small indent or depression in the ground merely by the revolution of it; but in order to make it press down to the depth of six or eight inches, that side of the cart should be loaded with stones, iron ballast, or any other heavy material that may happen to be at hand, until the whole of the parts, if necessary, sink into the soil. It would however be as well, or better, it is said, if the rim parts added to the wheel were in one piece of cast-iron; as the increased weight of it would enable it to cut or sink without the aid of ballast, or with less than usual. The cart should then be drawn along in such a manner, that the cutting or depressing wheel may revolve where the drains are intended to be made. In land that is in ridges and furrows, it will sometimes be necessary to draw the wheel along every

furrow. When the ground is without ridge and furrow, the wheel should be drawn over it in parallel lines, five or ten yards distant from each other. The wheel on the other end of the axle is a common six-inch wheel, supporting only the empty side of the cart, consequently will not cut or depress the ground.

The advantage of this contrivance is, that it makes an indent or depression in the surface soil of soft wet clayey grasslands, sufficient to carry off the water during the same winter, by pressing down the sward and herbage without destroying it. In the following spring, these drains will be nearly grown up, and clothed with grass; consequently, there will be nothing taken from the pasturage or the scythe. It is necessary to observe, that the wheel must be drawn over the ground every year on the approach of winter. With it, and two old horses, a stout boy or man may, it is said, drain from ten to twenty acres in eight hours.

It may be found very useful in the grass and hay land districts about the metropolis and other places. See *SURFACE Draining*.

WHEEL, Measuring. See *PERAMBULATOR*.

WHEEL, Orffyreus's. See *ORFFYREUS*.

WHEEL, Persian. See *PERSIAN*.

WHEEL-Ploughs, in *Agriculture*, all such ploughs as are constructed with wheels. See *PLOUGH*.

WHEEL, Potter's, is a round board attached to a lathe,

and capable of being moved by it, either rapidly or more slowly, as occasion may require. This round board moves in a horizontal position; and when in use, the clay which is to be fashioned is fixed on the centre of it; and it is put in motion either by a person who constantly attends it when at work, or by means of a treadle which is moved by the foot of the workman himself.

As the clay revolves upon this machine, the workman either models it by his fingers, or forms it, by means of an instrument which he holds in his hand, into any kind of circular shape that he may desire; and when the object is to make a number of vessels exactly similar to each other, the size is generally determined by a gauge fixed without the circumference of the revolving wheel, but projecting over it in such a manner that, whenever the yielding clay is spread out until it touch this gauge, the artist knows that the article which he is making has attained the exact figure which he intends.

The potter's wheel has lately been much improved by adapting a strap to it, which passes over a large taper cylinder of wood, and by means of which the artist is enabled to increase or diminish the rapidity of the motion at pleasure. This contrivance is known to mechanics by the name of the *cone pulley*. Parkes's *Essays*, vol. iii. See *POTTERY*.

WHEELS, Tires of, the iron hoops or bars which are put round the outides of the felly-parts of them.

Windmill

WIND-Mill, in *Mechanics*, a machine which is put in motion by the force of the wind. Wind-mills are in general applied to the purpose of grinding corn, but are occasionally used to give motion to machines for raising water, sawing-mills, or for other purposes. We shall in this article consider the wind-mill as a first mover, or *primum mobile*, which may be applied to many purposes.

The invention of wind-mills is not of very remote date. According to some authors they were first used in France in the sixth century; while others maintain that they were brought to Europe in the time of the crusades, and that they had long been employed in the East, where the scarcity of water precluded the application of that powerful agent to machinery.

The wind-mill, though a common machine, has some things in it more ingenious than is usually imagined. Add, that it is commonly allowed to have a degree of perfection, which few of the popular engines have attained to, and which the makers are but little aware of: though the aid of mathematics has furnished ample matter for its improvement.

The vertical wind-mill, which is the kind in most common use, consists of an axis or shaft A B, (*fig. 1. Plate II. Wind-Mill*;) placed in the direction of the wind, and usually inclining a little upwards from the horizontal line. At one end of this, four long arms or yards, S, T, V, W, are fixed perpendicular to the axis, and cross each other at right angles; into these arms small cross-bars are mortised at right angles; and other long bars are joined to them, which are parallel to the length of the arms; so that the bars intersect each other in the manner of lattice-work, and form a surface, on which a cloth can be spread to receive the action of the wind. These are called the sails; they are in form of a trapezium, and are usually nine yards long and two wide.

The circular motion is produced by the obliquity of the planes of these surfaces, from the plane in which all the four arms are situated; by these means, when the wind blows in the direction of the axis, it does not impinge upon the sails at right angles to their surfaces, but strikes obliquely; hence the effort of the sail to recede from the wind, causes it to turn round with the common axis, and the four sails are all made oblique in the same direction, so as to unite their efforts for the common object.

That the wind may act with the greatest efficiency upon the sails, the wind-shaft must have the same direction as the wind. But as this direction is perpetually changing, some apparatus is necessary for bringing the wind-shaft and sails into their proper position: this is done by turning the axis and sails round in an horizontal direction. There are two methods of effecting this. In the old mills, like *fig. 1*, the whole of the mill or building which contains the machinery is sustained upon a vertical post, firmly fixed as a stand or foot, upon which the whole machine can be turned by a lever, to prevent the sails to any quarter of the horizon from whence the wind blows; and hence these are called post wind-mills, and are necessarily made of wood. The other kind, *fig. 2*, is called a smock-mill, in which only the dome-cap or head, which contains the axis of the sails, and covers the great cog-wheel, turns round horizontally; the other parts of the machinery being contained in a fixed building, which rises up in form of a conical tower of masonry, and is surmounted by this moveable cap or dome, which is supported on rollers,

so as to turn round easily.

As both the common methods of adjusting the wind-shaft require human assistance, it would be very desirable that the same effect should be produced solely by the action of the wind. This may be done by fixing a large wooden vane or weathercock at the extremity of a long horizontal arm, which lies in the same vertical plane with the wind-shaft.

By these means, when the surface of the vane and its distance from the centre of motion are sufficiently great, a very gentle breeze will exert a sufficient force upon the vane to turn the machinery, and will always bring the sails and wind-shaft to their proper position. This weathercock, it is evident, may be applied either to machines which have a moveable roof, or to those which revolve upon a vertical arbor. This method is practised in small machines; but a vane of sufficient power to turn a large mill about would be unwieldy. A much better method is therefore practised in the best mills, as we shall soon describe.

In a *post-mill* the building must necessarily be of small size, and it can only contain one pair of mill-stones. For this purpose, a large cog-wheel is fixed upon the main-shaft or axis of the sails; the cogs are placed in the face or flat surface of the wheel, and act upon the teeth of a pinion, which is fixed upon the vertical axis or spindle of the mill-stones. The mill-house is of a rectangular figure, but narrow in the direction which is presented to the wind: it is two stories high, the main-shaft and mill-stones being in the upper chamber, whilst the lower is only used to contain sacks of flour, and also to receive the post on which the mill turns round horizontally to face the wind. This post is a very strong tree, and is held perpendicularly by fixing it upon the middle of long timbers, which form a large cross on the ground, and are the basement of the whole mill. The post is fixed perpendicularly by means of several oblique braces, extending from the ground-cross to the middle part of the post; but ten or twelve feet of the upper end of the post must be round, and clear from the obstruction of the braces. This part of the post rises up through the middle of the lower chamber, in the floor of which a circular collar is formed, to surround the lower part of the post exactly. At the upper end of the post is a pivot or gudgeon, which enters into a socket fixed in the middle of the upper floor, and to one of the strongest cross-beams, because this beam must sustain the whole weight of the mill. In this manner, the whole mill can turn about upon the vertical post, but remains always in equilibrio. To make it firm, and prevent it from turning about at every moment, a strong framing is united by joints to the back part of the mill-house, and descends in a sloping direction till it touches the ground: this is furnished with steps, so that it serves as a broad ladder to ascend to the mill; but another use is to steady the mill, because the end of this frame, which is very heavy, rests on the ground, and short posts are fixed in a circle round the mill at regular intervals, to which the end of the ladder is fastened with cords. In order to turn the mill about, a rope is fastened to the end of the sloping ladder, and is carried up to the top of the mill in an inclined direction. By means of a strong lever, or a tackle of pulleys, this rope can be shortened, so as to lift up the ladder clear of the ground; and then, by pushing it like a long lever, the whole mill is turned round. To obtain more force, a small capstan is often provided to draw

a rope attached to the end of the ladder. This capstan is moveable, and is fastened at pleasure to any one of the posts which are fixed in the ground.

The internal mechanism of a post wind-mill is exhibited in *fig. 3. Plate II. Wind-Mill*. A H O is the upper room; H α the lower one; A B the axis passing through the mill; S, T, V, W, the sails, covered with canvas, set obliquely to the wind, and turning round in the order of the letters in *fig. 1*; C the cog-wheel, having about forty-eight cogs, which carry round the lantern E, having eight or nine rounds, together with its spindle G N; K is the upper mill-stone, and L the lower one; Q R is the bridge supporting the axis or spindle G N; this bridge is supported by the beams *c* and X Y, wedged up at *c* and Q; *z* Y is the lifting-tree, which stands upright; *a b* and *e f* are levers, whose centres of motion are *a* and *u*; *f g h i* is a cord, with a stone, *i*: it goes about the pins *g* and *h*, to wind up and raise the stone at pleasure. The spindle *t* N is fixed to the upper mill-stone K, by a piece of iron called the rynd, and fixed in the lower side of the stone, which is the only one that turns about, and its whole weight rests upon a hard stone, fixed in the bridge Q R at N. The trundle E, and axis G *t*, may be taken away; for it rests by its lower part at *t* by a square socket, and the top runs in the edge of the beam *w*. By bearing down the end *f* of the lever *f e*, *b* is raised, which raises *z* Y, and this raises Y X, which lifts up the bridge Q R, with the axis N G, and the upper stone K; and thus the stones are set at any distance. The lower immoveable stone is fixed upon strong beams, and is broader than the upper one: the flour is conveyed through the tunnel *n o* into a chest; P is the hopper, into which is put the corn, which runs along the spout *r* into the hole *t*, and so falls between the stones, where it is ground. The axis G *t* is square, which shaking the spout *r*, as it goes round, makes the corn run out; *r s* is a string going about the pin *s*, and serving to move the spout nearer to or farther from the axis, so as to make the corn run faster or slower, according to the velocity and force of the wind. And when the wind is great, the sails S, T, V, W, are only in part or one side covered; or perhaps only one half of two opposite sails. Toward the end B of the axis another cog-wheel may be fixed, with a trundle and mill-stones, like that already described; so that the same axis moves two stones at once; and when only one pair is to grind, the trundle E, and axis G *t*, are taken out from the other; *x y l* is a girt or gripe of pliable wood, fixed at the end *x*; and the other end *l* is tied to the lever *k m*, moveable about *k*; and the end *m* being put down, draws the gripe *x y l* close to the cog-wheel; and thus the motion of the mill is stopped at pleasure; *p q* is a ladder for ascending to the higher part of the mill; and the corn is drawn up by means of a rope, rolled about the axis A B, when the mill is at work.

The structure of the mill-stones, or grinding parts, is the same as the water-mills. See *MILL*.

It is plain that this construction confines all the machinery to the two chambers, or that part of the mill which is poised upon the vertical post; hence this kind of wind-mill is unfit for any other purposes than that of grinding corn, and for expressing oil, because there is so little room for the machinery. The Dutch, who are famous for wind-mills, make them sometimes with a very large post, which has a hole down through the centre of it, like a trunk, and through this, a perpendicular axis passes to convey the power of the mill down into a building below, and upon the top of which, as a roof, the foundation-beams of the

post are fixed. (See *fig. 4.*) In this way, the mill is applied to saw wood, or to make paper, or any other purpose; but the construction is complicated, and less effective than the other kind of mill, in which only the head or top turns round, as we shall now describe.

The Smock-Mill.—This is the best kind of mill, because the building which contains the machinery may be made of any required dimensions, the sails and turning cap being all at the top of the house. *Fig. 3. in Plate I. Wind-Mill*, is a vertical section of one of these mills. K K are the walls of the house, and O O strong timbers forming a roof to it; upon these eight principal timbers H are erected, to form an octagonal pyramid of carpentry, the sides of which are filled up by diagonal bracing, and small uprights to nail the boarding to.

The four sails are fixed on an iron axis B N, by screwing them to an iron cross formed at one end of it. Two of these sails are marked A A; but the other two are endways, and cannot be seen. Upon the axis within the mill the cog-wheel C is fixed; and this turns a trundle or lantern D, fixed on the upper end of a strong vertical shaft, E E, extending from the top to the bottom of the mill, to turn the machinery: on the lower end of it is a large wheel, *f f*, which turns two pinions, *g g*, upon the spindles of the mill-stones *h h*. These are on the same construction as those described in our article *MILL*, to which we refer. At *l* is a wheel upon the main axis, giving motion to a pinion on a horizontal shaft or roller, *k*, which has a rope wrapped upon it, to wind up the sacks of corn. The wheel *l* also turns a similar horizontal axis with several wheels, to receive endless ropes for turning the bolting and dressing machines.

We will now enter more fully into the mechanism of the upper part of the mill, which is called its head or cap, marked G, and contains the axis B N. This is supported upon bearings, one being near its sails, and the other at its extreme end, as is shewn in *fig. 5. Plate II. Wind-Mill*, which is an horizontal section of the head, shewing the circular kirk, or wooden ring, K, and the framing which is bolted upon it to support the axis.

The construction of the axis is shewn in *fig. 6.* of the same plate. It consists of an octagonal iron shaft with two cylindrical necks at *c* and *d*, where it rests upon its bearings. At the end it has a kind of box, which has two mortises, *e* and *f*, through it in perpendicular directions to receive the sails. At the back of one of these mortises, and the front of the other, a projecting arm is left in the casting to receive screw-bolts, which hold the sails fast in the mortises. The cog-wheel is fixed on by bolting its arms against a flanch C, cast on the axis. The sails are braced by a rope-stay to each arm, proceeding from the end of a pole, which is fixed at the end of the cast-iron axis. Each sail is formed of a sail-cloth, spread upon a kind of lattice-work or framing, composed of rails mortised into the arms of the sails. The plane of this frame is inclined to the plane of the sails' motion at such an angle, that the wind blowing in the direction of the axis acts upon the sails as inclined planes, and turns them about with a power proportionate to the size of the sails and force of the wind. It is necessary, as the wind changes its direction, to turn the sails about, that the axis may be always in the direction of the wind. (See *fig. 3. Plate I.*) This motion is effected by turning the head of the mill round upon the fixed part, on a circle or kirk at the top of the frame composing the house of the mill. At the bottom of the frame of the wood-cap is a circular or moveable kirk, between which and the fixed kirk a number of rollers are placed; and the moveable kirk of the cap lies upon these rollers, which are kept

equidistant from each other by their centre-pins being fitted into a circular hoop: by these means, though the head of the mill with the wheels and sails weigh several tons, they can be made to turn round to face the wind by a slight power.

The head is contrived to turn itself about whenever the wind changes in the following manner:—A small pair of sails, or fans, *M*, are fixed up in a frame *L*, projecting from the back of the head: it has a pinion of ten leaves upon its axis, engaging in a wheel of 60 teeth upon an inclined axis *b*; and this has a pinion *d* of 12 leaves at the other end of it, turning a bevelled wheel of 72 teeth upon a vertical iron axis, at the lower end of which is a pinion *e* of 11 teeth: this works in a circle of 120 cogs, fixed round on the outside of the fixed kirk. By these means, whenever the fan *M* is turned, it moves the head of the mill slowly round, and with proportionate power.

Now if ever the wind varies in the least from the direction of the main shaft of the sails, it acts obliquely upon the vanes of the fan, and turns them round, at the same time setting the head right again, so that the axis points to the wind. But when the axis is in this situation, the wind blows in the planes of the vanes of the fan, and has no effect upon them. The head of the mill is kept firmly in its place when it turns about by rollers; the axes of which are bolted to the inside of the framing of the head, and the rollers apply to the inside of the fixed kirk: there are four of these rollers. The pivot at the upper end of the vertical shaft is supported in a bearing bolted to a cross-beam in the framing of the head of the mill; and this is fixed precisely in the centre of the head, that it may not vary in its situation as the head turns round. Many other things are so evident in the drawing as to need little farther explanation; such as the different floors of the building, and the circular gallery, *I I*, all round the mill, for the miller to go round to take the cloth off the sails in high winds, or when the mill is to stop. This is done by untying the cloth at the extremity of the sail, and twisting it up like a rope; then tying the end of it again to the lattice, in which state it presents no surface to the wind. At *k* is a roller turned round by a wheel *l*, fixed on the middle part of the vertical shaft: it is used to draw up the facks of corn from the bottom of the mill into the upper part, which is used as a store-house for the corn, being divided into as many compartments as the miller requires. The mill-stones are made the same as those used in water-mills. A pair of regulating balls are attached to the upper part of the mill-stone spindle, to regulate the velocity of the mill. The manner of applying this regulator is explained in *fig. 5. Plate II. Wind-Mill*. The lower end of the iron spindle *F* is fitted to a square, formed on the top of the mill-stone axis, and the pinion *g g* is fixed on the upper end, to give motion to the stones: immediately beneath the pinion two rods are jointed, hanging downwards, having a heavy iron ball, *l*, fixed fast on the lower end of each: two links are jointed to the arms at *m*, and suspend a collar, which is capable of sliding freely up and down upon the spindle *F*. It is evident that when the balls fly out from the spindle by their centrifugal force, that the collar will be elevated, and the contrary when the balls approach the spindle. The sliding collar is embraced by a fork formed at the end of a steelyard, lying horizontal, and suspended by the rod *p* as a fulcrum; an iron rod *q* descends from the extreme end of the steelyard, having its lower end formed to a hook, by which it is connected with a lever, *r*, whose fulcrum is *s*; this, by an iron rod *t*, suspends one end of the beam called the bridge, on which the lower pivot of the mill-stone axis rests, the other end bearing on a fulcrum or centre. Now it follows from this arrangement of levers, that by elevating the forked end

of the steelyard, or the sliding collar, that the spindle of the stones will be suffered to descend a very minute quantity. This regulates the velocity of the mill, because when the wind increases, and the motion of the mill is accelerated, the balls fly out by the centrifugal force; this lets the upper stone down nearer to the lower, thereby increasing the resistance to the mill, and counteracting the increased force of the wind. On the other hand, if the wind falls, and the mill moves more slowly in consequence, the balls fall together, and let down the sliding collar; this raises the stone up, and increases the distance between them, thereby diminishing the resistance; for this purpose, a weight *o* (*fig. 5.*) is hung upon the steelyard, sufficient to elevate the stone whenever the closing of the balls and consequent descent of the collar will permit it to do so. There are several notches made in the steelyard for different positions of the fulcrum *p* and rod *q*; by means of these the quantity of the regulation can be adjusted to the following rule. If when the wind blows stronger the mill goes slower, contrary to the effect expected, it shews that the regulation is too active; then increase the leverage of the balls by shortening the distance between the fulcrum *p* of the steelyard and the suspension of the rod *q*, by shifting either of them into different notches. On the contrary, if the mill goes much faster when the wind increases, it shews that the regulation does not act sufficiently; then increase the distance between the rod *q* and the fulcrum *p*. If the whole limits of the notches in the steelyard should not be sufficient to effect this, the acting length of the lever *r s* must be increased or diminished by removing its fulcrum *s* to a greater or lesser distance from the suspending-rod *t*; by means of this contrivance the miller is enabled, without much inconvenience, to regulate the velocity of the stones to that degree which is found best for reducing the greatest quantity of grain to flour, without damaging it by heating, as is the case when the stones move too quick.

Theory of the Motion of a Wind-Mill, with the Position of its Sails or Vanes.—The angle which the surfaces of the sails are to make with their common axis, that the wind may have the greatest effect, or the degree of weathering, as the millwrights call it, is a matter of nice inquiry, and has much employed the thoughts of the mathematicians.

To conceive why a wind-mill moves at all, the theory of compound motions must be supposed. A body moving perpendicularly against any surface, strikes it with all its force. If it move parallel to the surface, it does not strike it at all: and if it move obliquely, its motion, being compounded of the perpendicular and parallel motion, only acts on the surface, considered as it is perpendicular, and only drives it in the direction of the perpendicular. So that every oblique direction of a motion is the diagonal of a parallelogram, whose perpendicular and parallel directions are the two sides. Add, that if a surface, which, being struck obliquely, has only received the perpendicular direction, be fastened to some other body, so as that it cannot pursue its perpendicular direction, but must change it for some other; in that case, the perpendicular itself becomes the diagonal of a new parallelogram, one of whose sides is the direction which the surface may follow; and the other, that which it cannot.

Thus, a rudder fastened obliquely to the keel of a vessel, being struck by the current of water parallel to the keel, and, of consequence, obliquely with regard to itself; it will appear, by drawing the line of perpendicular impulse, that it tends to tear the rudder from the keel, and to carry it away: and that this direction, perpendicular to the rudder,

der, is oblique to the keel. The rudder, then, would be carried off in an oblique direction; but as, in reality, it is so secured, that it cannot be torn and carried off, we are only to consider, in this compound motion, that of the two directions wherewith it can move without being torn from the keel; and leave the other, which would tear it off, as useless.

Now, the direction in which it can move without parting from the keel, is that which carries it circularly about its extremity, as about a centre. So that the effect of the oblique impulse of the water on the rudder is reduced, first to a perpendicular impression, which is again reduced to the mere turning of the rudder round; or, if the rudder be immoveable, to the turning of the vessel. Now, in an oblique and compound motion, where only one of the directions is of service; the greater ratio the other has to it, the less effect will the motion have, and *vice versa*. In examining the compound motions of the rudder, we find, that the more oblique it is to the keel, the ratio of the direction that serves to turn it to the other is the greater. But, on the other hand, the more obliquely it is to the keel, and, of consequence, to the course of the water which is supposed parallel to it, the more weakly it strikes. The obliquity of the rudder, therefore, has, at the same time, both an advantage and a disadvantage; but as those are not equal, and as each of them is still varying with every different position of the rudder, they become complicated variously; so that sometimes the one prevails, and sometimes the other.

It has been a point of inquiry to find the position of the rudder, in which the advantage should be the greatest. M. Renau, in his famous theory of the working of ships, has found, that the best situation of the rudder is, when it makes an angle of fifty-five degrees with the keel. See RUDDER.

If, now, a wind-mill, exposed directly to the wind, should have its four sails perpendicular to the common axis in which they are fitted, they would receive the wind perpendicularly; and it is visible that impulse would only tend to overturn them. There is a necessity, therefore, to have them oblique to the common axis, that they may receive the wind obliquely.

For the greater ease, let us only consider one vertical sail. The oblique impulse of the wind on this sail is reducible to a perpendicular impulse; and that direction, as the sail cannot absolutely keep to it, is compounded of two; one of which tends to make it turn on its axis, and the other to fall backwards. But it is only the first of these directions that can be obeyed. Of consequence, the whole impulse of the wind on the sail has no other effect but to make it turn from right to left, or from left to right, as its acute angle turns this way or that. And the structure of the machine is so well contrived, that the three other sails are determined, from the same causes, to move the same way.

The obliquity of the sails, with regard to their axis, has precisely the same advantage and disadvantage with the obliquity of the rudder to the keel. And M. Parent, seeking, by the new analysis, the most advantageous situation of the sails on the axis, finds it precisely the same angle of fifty-five degrees.

For the farther illustration of this point, let A B (*Plate II. Wind-Mill, fig. 7.*) be the axis of the mill, C D a sail, and its angle of obliquity (*viz.* that which it makes with the axis) be E C G; then if G C be the force of the wind in the direct position of the sail, G E (the sine of the angle of incidence G C E) will be the force of the wind in its oblique position; but the force of G E is resolvible into two

others, E F and G F; of which the latter, being parallel to the axis, avails nothing in turning the sails about it; but the other, E F, being perpendicular to it, is wholly spent in compelling the sail to turn round. The force of the wind on the sail will be as the square of the sine of incidence, or as GE^2 ; and if the area of the sail, and the velocity of the wind, be supposed constant, the force of the wind in the direct position will be to that in the oblique one, as G C to G E; but when G E is the whole force, that part which turns the sail is represented by E F;

$$\text{and } GE : EF :: GC : CE :: GE^2 : \frac{CE \times GE^2}{GC}$$

= to the force which turns the sail, when the whole

force is represented by GE^2 . This expression $\frac{CE \times GE^2}{GC}$

begins from nothing, when the angle of incidence begins to be oblique, and increases with the obliquity of the said angle to a certain number of degrees; because that part of the force which is parallel to the axis, becomes less in proportion to that which is perpendicular to it; but after it has passed this limit, it again decreases, and becomes nothing, when the angle of incidence vanishes. There is, therefore, one certain position of the sail, in which the force of the wind upon it is a *maximum*. In order to find this, put radius G C = a , E C = x ; and we have $GE^2 = aa - xx$, and consequently the

$$\text{force } \frac{CE \cdot GE^2}{GC} = \frac{ax - xxx}{a}, \text{ which must be a } \text{maxi-}$$

mum: therefore its fluxion $-3x^2 = 0$: whence

$$aa = xx, \text{ and so } x = \sqrt{\frac{aa}{2}} = (\text{in logarithms})$$

$$\frac{20.000000 - 0.477121}{2} = 9.761439, \text{ which is the loga-}$$

rithmic sine of the angle $35^\circ 16' = CGE$; and therefore the angle $ECG = 54^\circ 44'$, when the force of the wind is a *maximum*. Thus, also, if lm (*fig. 7.*) parallel to the axis Q M, be equal to a , and represent the whole force of the wind on the sail; this force is reduced to ln , and this again to no , which acts perpendicularly to the axis, and turns the sail. This force, putting $mn = x$,

is expressed by $\frac{aa - x^2}{a}$ and thus, as before, when it

$$\text{is a } \text{maximum}, x = \sqrt{\frac{aa}{3}} = a \sqrt{\frac{1}{3}}; \text{ and the angle}$$

$lmn = 54^\circ 44'$. Martin's Phil. Brit. vol. i. p. 220, vol. ii. p. 212.

This angle, however, is only that which gives the wind the greatest force to put the sail in motion, but not the angle which gives the force of the wind a *maximum* upon the sail when in motion: for when the sail has a certain degree of motion, it yields to the wind; and then that angle must be increased, to give the wind its full effect. Mr. Maclaurin, in his Fluxions, vol. ii. p. 734. has shewn how to determine this angle.

It may be observed, that the increase of this angle should be different, according to the different velocities from the axis to the extremity of the vane or sail. At the axis it should be $54^\circ 44'$, and thence continually increase, giving

the vane a twist, and so causing each rib of the vane to lie in a different plane.

It is observed, that the ribs of the vane or sail ought to decrease in length from the axis to the extremity, giving the vane a curvilinear form; so that no part of the force of any one rib be spent upon the rest, but all move on independent of each other. The twist above-mentioned, and the diminution of the ribs, are exemplified in the wings of birds. As the end of the sail nearest the axis cannot move with the same velocity which the tips or farthest ends have, although the wind acts equally strong upon them, Mr. Ferguson (Lect. on Mechanics, p. 52.) suggests, that perhaps a better position than that of stretching them along the arms directly from the centre of motion, might be to have them set perpendicularly across the farther ends of the arms, and there adjusted lengthwise to the proper angle. For, in that case, both ends of the sails would move with nearly the same velocity; and being farther from the centre of motion, they would have so much the more power, and then there would be no occasion for having them so large as they are generally made; which would render them lighter, and, consequently, there would be so much the less friction on the thick neck of the axle, when it turns in the wall.

M. Parent considered what figure the sails of a wind-mill should have, to receive the greatest impulse from the wind; and he determined it to be a sector of an ellipsis, whose centre is that of the axis, or arbor, of the mill; and the little semi-axis the height of thirty-two feet: as for the greater, it follows necessarily from the rule that directs the sail to be inclined to the axis, in an angle of 55 degrees.

On this foundation he assumes four such sails, each of which is one-fourth of an ellipsis; which, he shews, will receive all the wind, and lose none, as the common ones do. These four surfaces, multiplied by the lever with which the wind acts on one of them, express the whole power the wind has to move the machine, or the whole power the machine has when in motion.

The same manner of reasoning, applied to a common wind-mill, whose sails are rectangular, and their length about five times their breadth, shews, that the elliptic wind-mill has about seven times the power of the common one.

A wind-mill with six elliptic sails, he shews, would still have more power than one with only four. It would only have the same surface with the four, since the four contain the whole space of the ellipsis as well as the six. But the force of the six would be greater than that of the four, in the ratio of 245 to 231. If it were desired to have only two sails, each being a semi-ellipsis, the surface would be still the same; but the power would be diminished by near one-third of that with six sails, because the greatest of the sectors would much shorten the lever with which the wind acts.

Best Form and Proportion of rectangular Wind-Mills.—As elliptical sails would be something so new, that there is little room to expect they will come into common use, the same author has considered which form, among the rectangular ones, will be the most advantageous. And by the method *de maximis et minimis*, he finds it very different from the common ones.

The result of this inquiry is, that the width of the rectangular sail should be nearly double its length; whereas the length is usually made almost five times the width. Add, that as we call length the dimension which is taken from the centre of the axis, the greatest dimension of the new rectangular sail will be turned toward the axis, and the

smallest from it; quite contrary to the position of the common sails.

The power of a wind-mill with four of these new rectangular sails, M. Parent shews, will be to the power of four elliptic sails, nearly as 13 to 23; which leaves a considerable advantage on the side of the elliptic ones; yet will the force of the new rectangular sails be considerably greater than that of the common ones.

M. Parent likewise considers what number of the new sails will be most advantageous; and finds, that the fewer the sails, the more surface there will be, but the less power. The ratio of the power of a wind-mill with six sails will be to another with four, nearly as 14 to 13. And the power of another with four will be to that with two, nearly as 13 to 9.

For a variety of curious experiments and observations concerning the construction and effects of wind-mill sails, by the ingenious Mr. Smeaton, see Phil. Trans. vol. ii. p. 138, &c.

Mr. Smeaton's experiments did not realize M. Parent's theory; for he found the sails fixed at the angle of 55 degrees with the axis, to be the least advantageous of any which he tried; but if the sails are included from 72 to 75 degrees from the axis, or 15 to 18 degrees to the place of their motion, the greatest effect will be produced that can be when the sails are plane surfaces.

He also found, that the elliptical sails, which intercept the whole cylinder of wind, do not produce the greatest effect, for want of proper interstices for the wind to escape.

The following maxims, deduced by Mr. Smeaton from his experiments, contain the most accurate information upon the subject.

Maxim 1.—The velocity of wind-mill sails, whether unloaded or loaded, so as to produce a maximum effect, is nearly as the velocity of the wind, their shape and position being the same.

Maxim 2.—The load at the maximum is nearly, but somewhat less than, as the square of the velocity of the wind, the shape and position of the sails being the same.

Maxim 3.—The effects of the same sails at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind.

Maxim 4.—The load of the same sails at the maximum is nearly as the squares, and their effects as the cubes of their number of turns in a given time.

Maxim 5.—When sails are loaded, so as to produce a maximum at a given velocity, and the velocity of the wind increases, the load continuing the same: 1st, The increase of effect, when the increase of the velocity of the wind is small, will be nearly as the squares of those velocities. 2dly, When the velocity of the wind is double, the effects will be nearly as 10 to 27½. But, 3dly, When the velocities compared are more than double of that where the given load produces a maximum, the effects increase nearly in the simple ratio of the velocity of the wind.

Maxim 6.—In sails where the figure and positions are similar, and the velocity of the wind the same, the number of turns in a given time will be reciprocally as the radius or length of the sail.

Maxim 7.—The load at a maximum that sails of a similar figure and position will overcome, at a given distance from the centre of motion, will be as the cube of the radius.

Maxim 8.—The effects of sails of similar figure and position are as the square of the radius.

Maxim 9.—The velocities of the extremities of the sails, in all their usual positions, when unloaded, or even

loaded to a maximum, are considerably quicker than the velocity of the wind.

Rules for modelling the Sails of Wind-Mills.—Fig. 4. Plate II. Wind-Mill, is a front view of one of the four sails of a wind-mill. The letters of reference will serve to explain the terms made use of in the following description.

1. The length of the arm or whip *AA*, reckoned from the centre of the great shaft *B*, to the outermost bar *19*, governs all the rest.

2. The breadth of the face of the whip *A*, next the centre, is one-thirtieth of the length of the whip; its thickness at the same end is three-fourths of the breadth; and the back-side is made parallel to the face for half the length of the whip, or to the tenth bar; the small end of the whip is square, and as its end is one-sixtieth of the length of the whip, or half the breadth at the great end.

3. From the centre of the shaft *B*, to the nearest bar *1* of the lattice, is one-seventh of the whip; the remaining space of six-sevenths of the whip is equally divided into nineteen spaces, so as to make nineteen bars; one-ninth of one of these spaces is equal to the mortises for the bars, the tenons of which are made square where they enter and go through the whip, and consequently the mortises must be square also.

4. To prepare the whip for mortising, strike a gage-score at about three-fourths of an inch from the face on each side, and the gage-score, on the leading side *4, 5*, will give the face of all the bars on that side; but on the other side, the faces of all the bars will fall deeper than the gage-score, according to a certain rule. To find the space to be set off for this purpose for each bar, construct a scale in the following manner.

5. Extend the compasses to any distance at pleasure, so that six times that extent may be greater than the breadth of the whip at the seventh bar; set those six spaces off upon a straight line for a base, at the end of which raise a perpendicular; set off three spaces upon the perpendicular, and divide the two spaces that are farthest from the base line into six equal parts each, so that this quantity of two spaces may be equally divided into twelve spaces marked out by thirteen points; from each of these points draw a line to the opposite end of the base, as so many rays to a centre, and the scale is finished.

6. To apply this scale to any given case, set off the breadth of the whip at the last bar, (that is, the bar at the extremity of the sail,) from the centre of the scale along the base towards the perpendicular; and at this point raise a perpendicular to cut the ray nearest to the base; also set off the breadth of the whip at the seventh bar in the same manner, and at this point erect another perpendicular to cut the thirteenth radius. From the intersection of the perpendicular (drawn upon the breadth of the last bar) with the first of the thirteen radii, to the intersection of the other perpendicular with the thirteenth radius, draw an oblique line cutting all the rest, and the distances of each of these last-mentioned points of intersection from the base line is the space which the face of each bar is distant from the gage-line on the driving side.

7. These distances give a different set-off for each bar till the seventh, which same must be set off for all the rest to the first.

8. The mortises must be square to the leading side of the whip.

9. When the mortises are cut, let the face of the whip be sloped off so as to agree with the face of the bars in every part.

10. Two-fifths of the whip are the length of the last or longest bar.

11. Five-eighths of the longest bar must be on the driving side of the whip, and three-eighths on the leading side, each being reckoned from the middle of the whip.

12. The proportion of the mortises already given determines the size of the bars at the mortises, but their thickness must be diminished each way, so as to be only one-half at the ends; but the face must be kept of equal breadth all the way.

13. The leading side goes no farther than the fourth bar, and there only projects one-third of the projection of the last bar.

14. All the bars on the driving side are made hollowing in the arch of a circle, which begins to spring one-third of the length of the bars on the driving side from the whip; and the sweep is such, that if a straight line is applied to the face of the bar from the whip to the end, the face of the bar should leave the straight line about the breadth of the bar.

15. There ought to be three uplongs, as *3, 2, 10, fig. 4*, to the driving, and two to the leading side, as at *5, 4*, to strengthen the lattice.

Self-regulating wind-mills are those which adapt themselves to the irregularities of the wind, by diminishing or increasing the surface on which the wind can act to turn them round. If the wind increases in force, the surface exposed to its action is diminished; on the contrary, if it decreases in force, the surface will be increased in the same proportion, so as in some measure to render their motion uniform.

The following self-regulating wind-mill is stated as the invention of Mr. Andrew Mickle in 1772, the inventor of the threshing-machine. The length of the sail was divided into eleven compartments, by the bars forming a number of oblong openings, which were each filled up by a square frame of wood covered with canvas, and mounted on pivots at their ends; one pivot turning in a hole in the whip, and the other in the bar which lies parallel to it, in the manner of a Venetian blind: the pivots were not placed in the middle of the breadth of the frames, but at one-third from that edge, towards the shaft or axis of the sails. On the end of each pivot which enters the whip a small roller is fixed, round which a chain passes, and its end is attached to a steel spring, placed at right angles to the whip, and in the direction of the length of the canvassed frames. Now, if the wind blows too hard, it acts to turn the frames edgewise, in which case the wind passes through the sails, and exerts less force to turn them round; but as soon as the wind becomes moderate, the steel spring brings up the frames into a plane, presenting their whole surface to its action. A rod of iron extends the whole length of the whip; and is connected with the several springs, to afford the means of strengthening or diminishing their action, according to the season of the year. This rod was formed into a screw at its outer extremity, and a nut put on to enable the miller to adjust the strength of the springs conveniently, from the circular gallery surrounding the outside of the mill.

Mr. William Cubit of North Walsham, in the county of Norfolk, took out a patent, in 1807, for a method of equalizing the motion of wind-mill sails. It is similar to Mr. Mickle's, in the sails being made like a Venetian blind; but instead of the springs, he applied racks and pinions on the ends of the blind pivots, and a sliding rod, which passed in a small hole made through the length of the axis of the sails; the end of this rod within the mill was

made into a rack, working in a wheel upon which a weight was hung. By this means, when the wind blows too hard, the blinds turn upon their pivots, and by the racks draw out the rod which passes through the axis, and raise the weight; but as soon as the wind abates, the weight brings the blinds to their former position.

A patent was granted in 1804 to Mr. John Bywater of Nottingham, for a method of clothing and unclothing the sails of wind-mills while in motion. The invention consists in a manner of rolling or folding up, and unfolding again, the cloths of common wind-mill sails while in motion. It is effected by placing a long roller in the direction of the length of the whip round which the cloth is rolled; the inner end of the roller is furnished with a pinion, which engages in the teeth of a circular ring of cogs fixed to the shaft-head, close behind the back-stocks, with the liberty of turning round independent of the shaft. Another roller is placed at the back-side of the sail, round which several cords pass, and are conveyed over pulleys at the edge of the sail, and then made fast to the cloth at different distances along its length. The object of this second roller is to clothe the sail, in the same manner as the first-mentioned roller unclothed it. The inner end of the back roller is furnished with a bevelled pinion, which acts in the teeth of a ring of cogs placed concentric with the one before described, which has also the liberty of turning round independent of the shaft. Suppose the sails to be completely clothed, and turning round by the wind, the two rings of cogs revolve with the axis, and therefore produce no effect on the pinions; but if the wind blows too violent, and it becomes necessary to partly unclothe the sails, the miller pulls a cord which is connected with a lever in the head of the mill. This lever comes in contact with a projection on the ring of cogs belonging to the rollers, upon which the cloth winds. Now it is evident, that if the ring of cogs is held fast, and the sails continue to revolve, it will cause the pinions to turn round and roll up the cloth upon the rollers; on the contrary, if the wind falls, the sails will require to be more clothed, which is effected by the same lever being moved farther, so as to quit the ring of cogs it held before, and hold the other fast, which will put the rollers at the back of the sails in motion, and by winding the cords upon them, draw the cloth off the sail-roller, which increases the surface for the wind to act upon. We have not entered into the minute details of this invention, as given in the patent, for it would have exceeded our limits, but only given a sufficient description to enable a person to understand the means of effecting the regulation.

Horizontal Wind-Mills.—These are of various kinds; but only one kind that we know of has been put to any valuable use.

Horizontal wind-mills were a favourite speculation a century ago; and the *Theatrum* of the celebrated Leopold contain a great variety, but they are all upon one or other of two principles. In one of these, a very large wheel, like a water-wheel, is mounted with its axis in a perpendicular direction. It consists of several circular wheels fixed upon the axis; and it has large boards or vanes fixed parallel to its axis, and arranged at equal distances round the circular wheels. Upon these vanes the wind can act to blow the wheel round; but if the wind were to act upon the vanes at both sides of the wheel at once, it would have no tendency to turn the wheel round; hence one side of the wheel must be sheltered from the wind, whilst the other is submitted to its full action. For this purpose, the whole wheel is inclosed within a large cylindrical framing of wood,

which is furnished with doors or shutters on all sides to open at pleasure, and admit the wind, or to shut and stop it. If all the shutters on one side are open, whilst all those on the opposite side are shut, the wind, acting with undiminished force on the vanes at one side, whilst the opposite vanes are under shelter, turns the mill round; but whenever the wind changes, the disposition of the open vanes must be altered, to admit the wind to strike upon the vanes of the wheel in the direction of a tangent to the circle in which the vanes move. A horizontal wind-mill is thus described in Leopold's *Theatrum Machinarum* for grinding corn with one pair of stones. A strong upright axis is so poised on a pivot at the lower ends, and sustained in a collar or bearing, as to turn round. Into this several long arms are fixed, in the manner of radii, and at the extreme ends of each arm a vane is fixed, to receive the action of the wind. These vanes are made of two or more moveable leaves, which close up flat like a book, when they are at that side of the circle which moves in a direction to advance towards the wind; so that only the edges of the boards are opposed to the wind; but when these vanes arrive at the opposite side of the wheel, so that the wind blows upon them, the leaves fly open, and expose their full surfaces to the wind, and receive the impulse thereof.

A horizontal wind-mill is described by Dr. Hooke in the *Philosophical Collections* for 1681. It consisted of four vanes mounted upon vertical axes, and arranged round in a circle by the upper and lower pivots of the vanes being received into holes in the rims of two horizontal wheels fixed upon the same vertical shaft. The vanes were disposed in such a manner, that on one side of the wheel each vane presented its surface to the wind, whilst the one on the opposite stood edgewise, so as to move through the air without much resistance. This was effected by cog-wheels placed on the lower pivots of the vanes, and so arranged, that as one vane turned round upon its pivots, the whole number moved together, and the motion was given to them by a cog-wheel fixed fast to the framing over the wheel, but concentric with it. This wheel communicated, by means of an intermediate wheel, with the wheels on the axes of the vanes.

The action of this machine is as follows:—Suppose the wind blowing at the wheel; it acts against that vane which is at right angles to its motion, to turn the wheel round upon its axis. The opposite vane presenting its edge to the wind opposes very little resistance. The motion of the wheel upon its axis turns the vanes round upon their pivots, by means of the fixed cog-wheel before described; so that by the time that one has passed out of the direction of the wind, another arrives in the same perpendicular position; and when the wheel has made half a revolution, the vane which stood edgewise will be perpendicular to the wind, and the one which before stood perpendicular will be edgewise; thus a continued motion is produced without the wheel being cased up.

Horizontal wind-mills, which are inclosed in a house with blinds on all sides, are very fully described in Jacob Leopold's *Theatrum Machinarum*, 1724; but we believe they were first practised in this country by captain Hooper, who erected one at Margate, and another at Battersea. The latter is upon a very large scale, and is used for grinding corn; but at present it does not work with much advantage, as the repairs are more considerable in proportion to the power it exerts, than in the mills with sails constructed in the common manner.

In *Plate Wind-Mill*, fig. 1, is an upright section, and fig. 2.

a plan of the horizontal mill erected at Margate by captain Hooper. H H are the side walls of an octagonal building which contains the machinery. These walls are surmounted by a strong timber-framing G G, of the same form as the building, and connected at top by cross-framing to support the roof, and also the upper pivot of the main vertical shaft A A, which has three sets of arms, B B, C C, and D D, framed upon it at that part which rises above the height of the walls. The arms are strengthened and supported by diagonal braces, and their extremities are bolted to octagonal wooden frames, round which the vanes or floats E E are fixed, as seen in outline in *fig. 2*, so as to form a large wheel resembling a water-wheel, which is less than the size of the house by about eighteen inches all round. This space is occupied by a number of vertical boards or blinds F F, turning on pivots at top and bottom, and placed oblique, so as to overlap each other, and completely shut out the wind, and stop the mill, by forming a close case surrounding the wheel; but they can be moved all together upon their pivots to allow the wind to blow in the direction of a tangent upon the vanes on one side of the wheel, at the time the other side is completely shaded or defended by the boarding. The position of the blinds is clearly shewn at F F, *fig. 2*. At the lower end of the vertical shaft A A, a large spur-wheel *aa* is fixed, which gives motion to a pinion *c*, upon a small vertical axis *d*, whose upper pivot turns in a bearing bolted to a girder of the floor N. Above the pinion *c*, a spur-wheel *e* is placed, to give motion to two small pinions *f*, on the upper ends of the spindles *g* of the mill-stones *h*. Another pinion is situated, at the opposite side of the great spur-wheel *aa*, to give motion to a third pair of mill-stones, which are used when the wind is very strong; and then the wheel turns so quick, as not to need the extra wheel *e* to give the requisite velocity to the stones. The weight of the main vertical shaft is borne by a strong timber *b*, having a brass box placed on it to receive the lower pivot of the shaft. It is supported at its ends by cross-beams mortised into the upright posts *bb*, as shewn in the plan, *fig. 2*. A floor, or roof, I I, is thrown across the top of the brick building, to protect the machinery from the weather; and to prevent the rain blowing down the opening through which the shaft descends, a broad circular hoop K is fixed to the floor, and is surrounded by another hoop or case L, which is fixed to the arms D D of the wheel. This last is of such a size, as exactly to go over the hoop K, without touching it when the wheel turns round. By this means, the rain is completely excluded from the upper room M, which serves as a granary, being fitted up with bins *mm*, to contain the different sorts of grain which is raised up by the sack-tackle. A wheel *i* is fixed on the main shaft, having cogs projecting from both sides. Those at the under side work into a pinion on the end of the roller *k*, which is for the purpose of drawing up sacks. Another pinion is situated above the wheel *i*, which has a roller projecting out over the flap-doors seen at *p*, in the *fig. 2*, to land the sacks upon. The two pinions *m m*, *fig. 2*, are turned by the great wheel *aa*, and are for

giving motion to the dressing and bolting machines, which are placed upon the floor N, but are not shewn in the drawing, being exactly similar to the dressing-machines used in all flour-mills. The cogs upon the great wheel *a* are not so broad as the rim itself, leaving a plain rim about three inches broad. This is encompassed by a broad iron hoop, which is made fast at one end to the upright post *b*; the other being jointed to a strong lever *n*, to the extreme end of which a purchase *o* is attached, and the fall is made fast to iron pins on the top of a frame fixed to the ground. This apparatus answers the purpose of the brake or gripe used in common wind-mills to stop their motion. By pulling the fall of the purchase *o*, it causes the iron strap to embrace the great wheel, and produce a resistance sufficient to stop the wheel. The mill can be regulated in its motion, or stopped entirely, by opening or shutting the blinds F, which surround the fan-wheel. They are all moved at once by a circular ring of wood situated just beneath the lower ends of the blinds upon the floor I I, being connected with each blind by a short iron link. The ring is moved round by a rack and spindle, which descend into the mill-room below, for the convenience of the miller.

A sort of wind-mill has been long much employed in Portugal, in which, from the difference in the construction of the sails, it is supposed by some, as lord Somerville, who has inspected it when working, to possess a superiority in having the broad part of the sail at the end of the levers or booms; in consequence of which equal resistance is overcome with less length of branches: and that from this shortness a considerable saving is made in the timber of both the booms and spindles, as well as in the height, first cost of the mills, and their future repairs.

The advantages of making use of these sorts of wind-mills in preference to others are, that as there are four booms, as well as four masts for the sails, they are capable of being more easily braced out to the wind, and in case of a sudden gale or gust of it, are more easily cast loose than in those of the common construction; and that as the sails in these mills are placed in the best possible direction by the booms, it is presumed that a wind-mill built on this plan and principle will do more work than any common wind-mill with an equal quantity of canvas.

These sorts of mills have also lately been very much improved by constructing and disposing those surface parts upon which the wind is intended to act, in such a particular manner, as that by alternately opposing a resisting and non-resisting surface, the whole force or impulse may operate in a direct manner upon the resisting side of the sail or vane, in proportion to its extent; and that when the non-resisting side is returning against these powers, the mill being so contrived that there is very little resistance, however large the surface. These improvements, when applied to horizontal wind-mills, the power of them, even with the same quantity of sail, or acting surface, may too be increased or diminished at pleasure, which is a circumstance of very great utility and convenience in many cases.

WIND MILL.

Fig. 3.

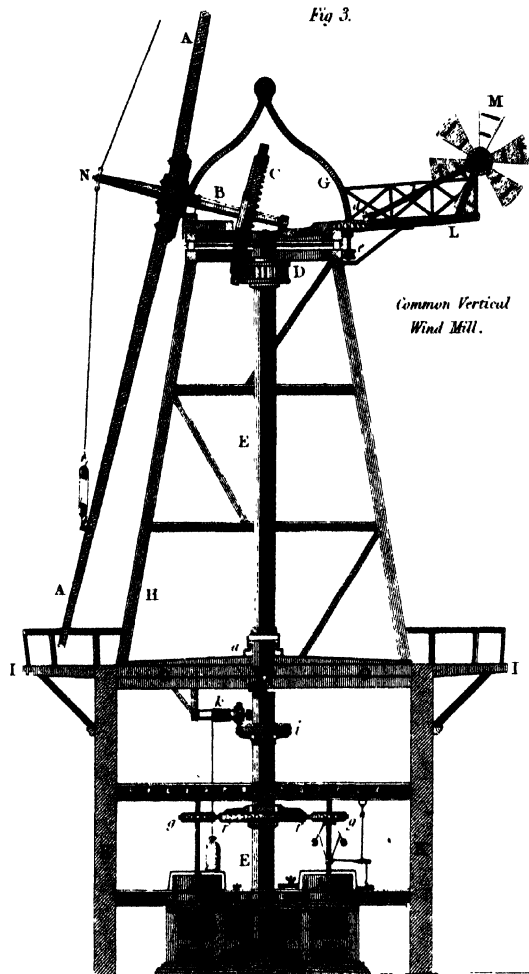


Fig. 1.

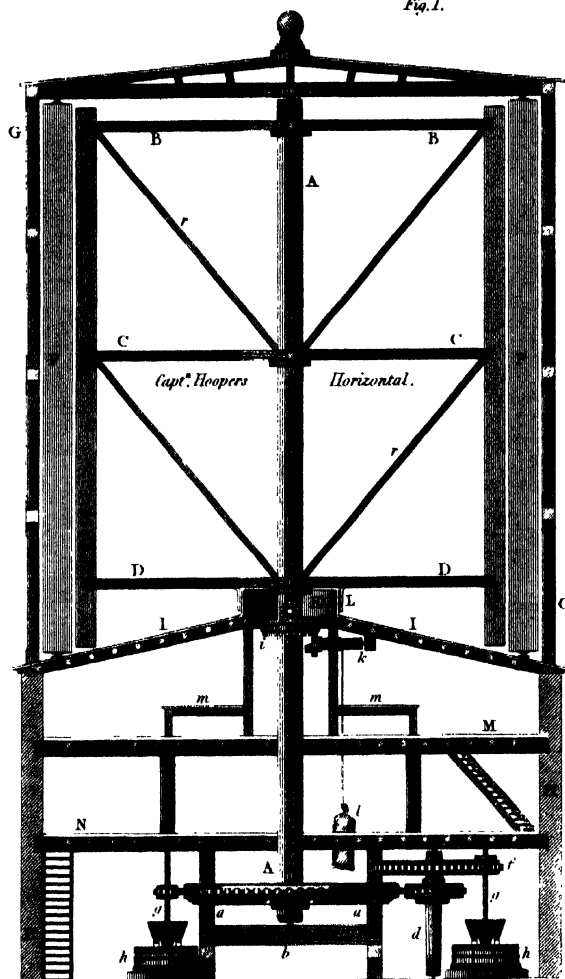


Fig. 5.

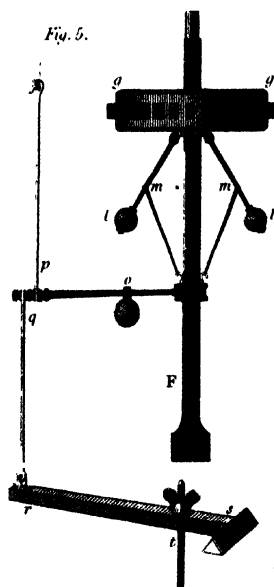


Fig. 4.

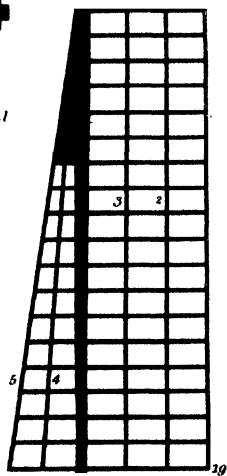
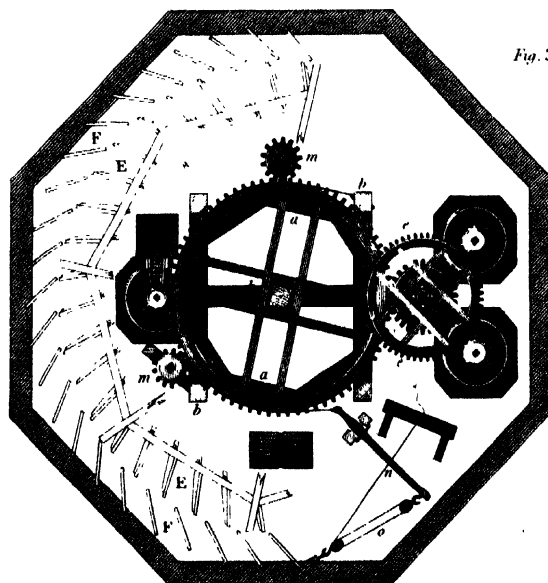


Fig. 2.



Wire

WIRE, in the *Mechanic Arts*, is a very useful preparation of different metals, in form of a regular and even thread, which can be obtained in very great lengths, and of any re-

quired size or shape.

Wire is made of any ductile metal, as platina, gold, silver, copper, brass, zinc, iron, or steel. The process of making

wire consists in drawing the piece of metal through a hole in a plate of steel, by which means the metal is rendered of an equal size, and either round or of any other figure corresponding with the figure of the hole in the draw-plate; the metal is thus reduced in size, and at the same time is lengthened in proportion. From the great regularity of wire, and from its toughness and ductility, it is extremely useful to all artists who work in metal.

The operation is called wire-drawing, and the plate of steel a draw-plate. The machine by which the wire is drawn is called a draw-bench.

The common draw-bench is of a simple structure. A strong plank of wood is fixed on legs, like a stool or bench, *fig. 1.* *Plate Wire.* At one end is a roller or axis, *A*, fixed in an horizontal position, so that it can be turned round by means of four levers, *B B*, fixed like radii on the end of the axis of the roller. If the resistance is great, the workman applies both his hands and his feet to the levers, to turn them round in the same manner as for a rolling-press. It is usual to have a strong strap, or chain, *C*, to wrap and wind up round the roller; and at the end of it a pair of pincers, *D*, are linked: these take hold of the end of the piece of metal, and draw it through the hole in the draw-plate *E*, which is lodged against two strong iron pins, *aa*, fixed in the bench, and standing up perpendicularly, so that the plate bears against them.

The pincers are shewn in *fig. 2.* They are adapted to bite the end of the wire; and the inside of the jaws, *dd*, are cut with teeth like a file, that they may hold the metal very tight. The opposite ends of the handles are bent in form of hooks at *ee*; and a triangular link of iron *f*, which is fastened to the end of the strap or chain *C*, embraces both hooks *ee*, and from its triangular figure, it tends to approach the two hooks at the ends of the tongs together: by these means, the strain of drawing the wire closes the pincers, and makes them bite more forcibly in proportion as the wire makes a greater resistance, so that they rarely let the wire slip.

The draw-plate, *figs. 3 and 4*, is a thick plate of steel, with holes made through it of various sizes, and in a regular gradation from the largest to the smallest. The holes are made large on that side where the wire enters, and they diminish with a regular taper to the other side; the goodness of the draw-plate is an object of the first importance. The different holes must diminish by very small gradations, or there will be danger of breaking the wire by forcing it too much at once.

In some draw-benches a rack and pinion are employed, instead of a strap or chain; and a train of wheel-work may be used like that of a crane to obtain a sufficient power. (See *fig. 5.*) If the workman turns the machine by a winch or handle, it is preferable to four levers, because the motion is more regular; this is of importance for some purposes. Suppose a piece of elastic metal is forcibly drawn through a hole in a plate with a tolerably quick motion, it will be compressed at the moment of passing through the hole; but after it quits the hole, the metal will expand a little. When it is drawn very slowly, this effect will not take place; for if the compression is continued long enough it becomes permanent: hence, if a piece of large wire be drawn with an irregular motion, first quicker, and then slower, it will be sensibly larger at all the parts which pass quickly through the hole, and smaller where it is drawn slowly: if the motion is suspended for a few seconds, that part of the wire which remains in the hole will have a ring or indentation round it. This is most obvious in drawing hollow tubes, or copper-wire, which is plated over with gold or silver.

In the machine which is used for drawing strong pieces

of metal, and for the very largest, the roller is usually placed in a vertical position, like a capstan, with four levers, at which several men push, whilst they walk round in a circle to turn the capstan, and wind up the chain which draws the wire through the draw-plate.

A powerful machine of this kind is described in our article *PIPES*, for drawing lead-pipe through a steel plate.

We have seen a very powerful wire-drawing machine used for forming large hollow tubes of brass or copper, on which the power to draw the tube was obtained by a screw, like that of a press. This screw was turned by a train of wheel-work, with a fly-wheel to regulate the motion.

Another plan, which is perhaps the best mode for a very powerful drawing-machine, is to apply the force of the hydrostatic machine originally invented by Pascal, and revived by the late Mr. Bramah. (See *MACHINE*, and *PRESS*.) By this means, very large wires for piston-rods of steam-engines, and other similar pieces, may be rendered straight and true with little expence.

All these machines are confined to draw pieces of metal, which are only a few feet in length, that is, the length of the bench. But when the metal by repeated drawing becomes lengthened into a regular wire, if it is required to reduce it to a still smaller size, it must be drawn through succeeding plates, by wrapping the wire itself upon the roller or barrel, instead of employing a long chain. This method is not applicable at first, because a thick bar of iron could not be made to bend easily round a roller; but when the wire becomes small and flexible, it can be practised very advantageously, and admits of drawing a very great length of wire by a small and commodious machine.

The common wire-mills used in France do not, however, employ a roller or windlafs, but the pincers are attached to a lever, which draws them backwards and forwards alternately by the power of the water-wheel.

The pincers are so constructed, that the jaws open when they move towards the draw-plate, and release themselves from the wire; but when the pincers are drawn back from the draw-plate, the link causes the pincers to close and bite the wire with such force, that they will draw it through the plate.

A machine of this kind is shewn in *fig. 7.* of the plate. The base of the machine is a very strong log of timber *R*; one end of it is cut open to receive a wooden lever *A B*, which moves round an iron pin or bolt *n*, as a centre of motion; this lever is shaped like the letter *L*. To the upright arm *A* of this lever, an iron link *C* is jointed, and the other end of this link is formed like a ring, to receive the handles of the pincers *D*. The pincers are supported upon a plate of iron *d*, which is placed in an inclined position, and there is a groove in the plate, into which the end of the pin or joint of the pincers is received, and they are by that means guided in their motion backwards and forwards: *aa* are the pins which support the draw-plate *E*; there are four of them, and the plate is fastened between them by wedges.

The end *B* of the lever is operated upon by cogs fixed on the axis of the water-wheel, which, as it turns round, depresses the end *B* of the lever; and the end *A* pulls the pincers back, and draws the wire through the draw-plate; but when the cogs quit the end of the lever, it is returned by means of a rope fastened to the end of *B*, and going up to a strong wooden pole fixed on the roof of the building; and it acts as a spring. When the pincers return, they open to release the wire, and slide down the inclined plate *d* by their own weight, till they are near the draw-plate; the wire being all the time included between the jaws, though

they do not bite. The next cog which seizes the end of the lever draws back the pincers, which immediately close upon the wire, and draw it through the plate.

A wire-mill usually contains three such machines of different sizes: the largest only draws two inches of the wire at each stroke, and makes about forty eight strokes in a minute; the second machine, four inches; and the third, five inches. This works quicker than the other two, and makes sixty-four strokes *per* minute. This is a simple machine, but very defective, for much time is lost in the returning of the pincers; they sometimes fail to take good hold of the wire, and they always make deep marks upon the wire at every place where they bite, which are not more than two inches distance in the great wire, and five inches in the smaller.

Fine wire is always made from large wire, by reducing it and lengthening it out by repeated drawings. The large wire is usually manufactured at the wire-mills in the country, and some part of it is reduced to small wire at the same establishments, but more commonly the large wire is bought by those who have occasion for it, and they reduce it by drawing until it becomes as small as it is wanted.

The hand-machine for this purpose, represented in *fig. 8*, is extremely simple. *A* is the roller on which the wire is wound up; it turns round upon a vertical pin, fixed in the bench *R*, and to the upper end a handle *B* is fixed, for the workman to turn it round; *E* is the draw-plate, and *a a* the pins against which it rests. The wire which is to be drawn is put upon a small circular reel *F*, which turns round upon a vertical pin; this pin is sometimes fixed in the table, or otherwise in a small cask containing starch-water, or beer which has become acid. The use of this is to loosen the oxyd from the surface of the wire, for it is necessary to anneal or soften the wire very frequently, by putting it in the fire, and this produces a black coat of oxyd on the surface, which will be removed when the wire is again drawn through the plate, and the wire will come out bright and clean. The removal of this oxyd will be facilitated by some slightly corrosive menstruum.

Fig. 9, is a very simple and complete wire-drawing machine, to draw three wires at once. *A R* are two rollers or barrels with cog-wheels, *T V*, on the ends of their axis, which wheels are engaged together. *S* is a pinion, which is turned round by means of a handle *B*, and gives motion to the wheels *T V*. Both these wheels are fitted upon round parts of the axis of their respective rollers, so as to slip or turn freely round upon the same; but a square is formed on the axis outside of the wheel, and a clutch or catch, *t* or *v*, is fitted on this square part, so as to turn always round with the axis. The catch is at liberty to slide upon the axis in the direction of its length, by means of a lever *W*, which operates upon both catches at once. When either of them is pushed back in contact with the wheel, it intercepts two studs which project from the face of the wheel, and then compels the axis and roller to turn round with the wheel; but when the catch is drawn away from the wheel, then the wheel will slip round upon its axis, without communicating any motion. By means of the lever *W*, only one wheel can be engaged at once, and the other must be free. The draw-plate *E* is firmly fixed between the two rollers, and it has a great many holes; the rollers are long enough to receive three wires at the same time. Each roller has a groove in it parallel to the axis, into which a bar of metal is fitted, and will exactly fill it up. When the wires are introduced through the holes in the plate, the ends are laid across this groove; the bar is then put in and fastened by a simple contrivance, and it

fastens the ends of the wires beneath it, so that they become attached to the roller; then by turning the handle *B* round, the two wheels are put in motion in contrary directions; and that wheel which is connected with its axle by its catch, will turn its barrel round, and wind up the wires so as to draw them through the plate *E*. The other roller being at the same time detached, its wheel is at liberty to turn round in a contrary direction to the wheel, as fast as the wires are drawn off from it. When the whole length of the wires has been drawn through the plate, they are detached from the roller, the ends introduced through smaller holes in the plate, and fastened again to the roller; then the lever *W* is shifted, to disengage that wheel which operated before, and engage the other. This being done, the rollers will be turned in an opposite direction, and will wind back the wires, although the handle *B* is turned the same way round.

After the wire has been then drawn three or four times, the metal becomes so hard and fibrous, that it would not draw any more without breaking; it therefore requires to be heated in the fire to restore its ductility; for this purpose it must be taken off the barrels. A roller *M* is provided to wind the wire upon and draw it off from the barrel; this roller is turned round by a handle *m*, fixed on the extremity of its axis; and the wire which is wound upon it in a coil is slipped off sideways. This machine is well adapted to be worked by a mill, because the handle may always be turned the same way.

Fig. 10, represents the machine used at the wire-mills for reducing the wire which is to be used for musical instruments, or for making cards for wool and cotton. The rollers *A* are situated in a vertical position, being fitted on the tops of iron spindles, which are sustained in a vertical position by bearings in the frame of the table or bench. These spindles are kept in continual motion by wheel-work situated beneath the bench, but the spindles are round, so that the rollers *A* are not turned with the spindles, unless any one of the rollers is lifted up upon the spindle. A cross-bar, which is fixed on the top of the spindle, then engages with two projecting knobs fixed in the roller, within a hollow recess made at the top of it, and turns the roller round. The draw-plate *E* is supported by two pins, as before described; and the wire which is to be drawn is wound on a reel, which is put into a cask of stale-beer grounds, or starch-water. The end of the wire, which is put through the draw-plate, is made fast to the roller, which does not turn round as long as it is dropped down upon the spindle; but when all is ready to begin drawing, the roller must be lifted up, and the clutch at the top of the spindle will engage with the two knobs within the hollow at the top of the roller. This puts it in motion, and draws the wire through the draw-plate. The strain of drawing is sufficient to keep the roller up upon the spindle; but as soon as the whole of the wire is drawn through the plate, the resistance ceases, and the roller drops down on its spindle, and becomes disengaged until the workman puts it again in action.

Manufacture of Iron Wire.—Iron is a very ductile metal, but requires a careful treatment in the process of wire-drawing, because it becomes very hard and brittle when the fibres are greatly compressed by repeated drawing. Its ductility must then be restored by heating the wire to redness; this is called annealing: it renders the wire soft, and it will then draw finer and longer; but it will soon require annealing again, and so on.

The iron which is selected for wire-drawing must be of good quality, to bear the requisite extension without breaking. It must be of an uniform substance, without any grains

of hard or soft parts. The softest iron is not always found the best, as it will diminish by the strain of drawing it through the holes alone; and to obviate this, the workman must draw such iron through a greater number of holes to obtain the required extension.

The iron is wrought at the tilt-mills from square bars into round rods of a proper size to commence drawing. The operation of tilting is nearly the same as *tilting of steel*. (See that article.) The tilt-hammer for a wire-work generally makes twenty strokes *per* minute, and weighs about fifty pounds. There is also a larger hammer worked by the same mill, which strikes about 130 times *per* minute, and weighs 100 pounds. This hammer is only used for the first preparation of the iron, or for welding a faggot of small bars together, in order to give the iron a better quality by a preparation similar to the German steel. To draw out the iron bars into rods of a proper size to begin drawing, the workman heats six or eight inches of the end of a large bar, which comes from the great forge where the iron is made, and when properly heated he works it regularly under the small tilt, until it is drawn out to a small and regular round rod of five or six feet in length. A good workman can thus draw out two hundred weight of iron in a day, or an ordinary workman one and a half hundred weight. The loss of metal in the operation is near 26 *per cent.* by weight.

The small rod, before it is cold, is taken by another workman, who straightens the rod with a hammer upon an anvil, then cuts it off, and places the end of the great bar again in the forge. This same workman also superintends the heating of the iron, and must be very careful not to overheat it, but to heat the whole regularly.

It is a good practice to pass the iron-rod through a pair of grooved rollers, the grooves of the two rollers being opposite, so as to form a round between them. By these means, the iron may be reduced small, and rendered very true, previously to beginning the drawing. For common wire, the whole reduction may be done by the rolling-mill without a tilt; but the hammer will give a more tenacious quality to the iron than can be obtained by rolling.

A small round bar, thus prepared, must be drawn through a hole in a draw-plate, by a strong machine with a chain, or else by the lever-machine, *fig. 7*. The end of the iron is first reduced, so that it will enter the hole in the draw-plate, and pass through sufficiently for the pincers to take hold. This is done at the forge by a hammer and anvil. By passing through the plate the wire becomes lengthened, in proportion as it is diminished in size. It must then be annealed to soften it, the end pointed anew, and again put through a smaller hole.

The workman who attends the process must study the nature of the iron, and regulate the manner of drawing accordingly. This he does by altering the figure of the hole through which the wire is drawn. The hole must be conical; the smallest part, being that which acts principally on the metal, must be at that side of the plate where the wire comes through. If the taper of the hole is not properly proportioned, the iron will be strained in drawing; for though the machine will force it through, grains of harder metal than the rest of the wire will form themselves, which will occasion the wire to break when it comes to be much reduced. This is particularly the case in soft iron. To avoid this, the hole must be chosen very little smaller than the iron, and must be made with a regular taper. It must be well supplied with grease, to diminish as much as possible the friction; and the motion of the draught must be regulated according as the metal will bear it.

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Much depends upon the quality of the draw-plate; although the metal of the plate is sufficiently hard to draw the wire, it will not resist the blow of a hard steel hammer and punch. The punch is driven into the hole from behind, until it enlarges it to the required size and figure. In the operation of drawing, the hole becomes gradually enlarged, and that in a greater degree at the smallest end of the hole, so that it becomes nearer to a cylinder. To rectify this, the punch must be applied, or the wire would not pass easily; that is, if the same degree of reduction in the size of the wire was attempted, it would break or strain the wire, if the hole was cylindrical, although it would pass through a regular taper hole. The hole sometimes wears irregularly, and loses its circular figure. In this case, the plate is hammered around the small end of the hole, and the hole is thereby reduced. The punch is then driven in, to enlarge it again to the required size: sometimes the punch is introduced at the small end, and then at the large end, as it may be required to form the hole. In all cases, the punch must be driven very gently; and after every stroke of the hammer it must be loosened in the hole, and turned round before another blow is struck, and without this precaution it would fix fast in the hole.

The French draw-plates are the most esteemed; and, in time of war, a good French draw-plate has been sold for its weight in silver. M. Du Hamel, in *Les Arts et Metiers*, vol. xv. gives the following account of the process of making the draw-plates for the large iron-wire.

A band of iron is forged of two inches broad and one inch thick. This is prepared at the great forge. About a foot in length is cut off, and heated to redness in a fire of charcoal. It is then beaten on one side with a hammer, so as to work all the surface into furrows or grooves, in order that it may retain the substance called the *potin*, which is to be welded upon one side of the iron, to form the hard matter on which the holes are to be pierced. This *potin* is nothing but fragments of old cast-iron pots; but those pots which have been worn out by the continued action of fire are not good: the fragments of a new pot which has not been on the fire are better.

The workman breaks these pieces of pots on his anvil, and mixes the pieces with charcoal of white wood. He puts this in the forge, and heats it till it is melted into a sort of paste; and to purify it he repeats the fusion ten or twelve times, and each time he takes it with the tongs to dip it in water. M. Du Hamel says, this is to render the matter more easy to break into pieces.

By these repeated fusions with charcoal, the cast iron is changed, and its qualities approach those of steel, but far from becoming brittle; it will yield to the blows of the hammer and to the punch, which is used to enlarge the holes. The bar of iron which is to make the draw-plate is covered with a layer of pieces of the *potin*, or cast iron, thus prepared. It is applied on the side which is furrowed, and should occupy about half an inch in thickness. The whole is then wrapped up in a coarse cloth, which has been dipped in clay and water mixed up as thick as cream, and is put into the forge. The *potin* is more fusible than the forged iron, so that it will melt. The plate is withdrawn from the fire occasionally, and hammered very gently upon the *potin*, to weld and in some measure amalgamate it with the iron, which cannot be done at once; but it must be repeatedly heated, and worked until the *potin* fixes to the iron. The workman then throws dry powdered clay upon it, in order, they say, to soften the *potin*.

The union being complete, the plate is again heated, and forged by two workmen, who draw out the plate of one

foot to a length of two feet, and give it the form it is to have. It is well known that cast iron cannot be worked at the forge without breaking under the hammer; but in the present instance, it is alloyed with the iron-bar, and is drawn out with it. It has also acquired new properties by the repeated fusions with charcoal.

The holes are next pierced whilst the plate is hot. This is done with a well-pointed punch of German steel, applied on that side of the plate which is the iron-bar. It requires four heats in the fire to pierce the holes, and every turn a finer punch is employed, so as to make a taper hole. The makers of draw-plates do not pierce the holes quite through, but leave it to the wire-drawers to do it themselves when the plate is cold, with sharp punches, and then they open the hole to the size they desire; and although this potin is of a very hard substance, the size of the hole may be reduced by gentle blows with a hard hammer, on the flat surface of the plate, round the hole.

A great many holes are made in the same plate; and it is important that they should diminish in size by very imperceptible gradations; so that the workman can always choose a hole suitable for the wire he is to draw, without being obliged to reduce it too much at once.

To ascertain the size of the wire, gauges are used. They are commonly made of a piece of wire bent in zigzag, as shewn in *fig. 11*; and the space between every bend is of a different width; but a better sort is made of a steel-plate, with notches on the edge. (See *fig. 12*. for the standards.) These should be hardened, that they may not be subject to wear.

Fig. 13. is another kind of gauge, which is very accurate. It consists of two straight rules of steel, put together at an angle. The diameter of the wire is indicated by the depth to which it will enter into the angle; the edges of the rulers are divided into equal parts for that purpose, and numbered, to correspond with the different sizes of wire.

The wire manufactory of Messrs. Mouchel, situated at l'Aigle, in the department de l'Orne, is one of the most considerable in France. It furnishes annually, in cards for wool-combing only, an hundred thousand quintals of iron-wire, each 100lbs. A part of this is consumed in France, and the rest is exported to Portugal, Spain, Italy, and even to the shores of the Levant.

They employ the iron manufactured in the departments of l'Orne and La Haute Saone, as being of the best quality. The first produces the best wire for making screws, nails, and pins, as much on account of its hardness as its fine polish, which resembles steel-wire. In this respect, it is superior to the iron of Haute Saone, but from its ductility the latter can now be made extremely fine, and it appears to be most free from heterogeneous particles.

The smelted iron, prepared and hammered, being in a state nearly fit for their purpose, is transported, at a small expense, to l'Aigle, by the rivers and canals. They have a forge to reduce the steel and iron of Normandy, which arrives in large pieces, into small and regular bars.

When the iron is formed into an irregular bar of about a centimetre, near four-tenths of an inch in diameter, they begin to draw it into wire. Although it be already much extended by hammering, it is in the first place passed four times through the drawing-plate; then its molecules become disposed lengthways, and exhibit fibres at their utmost extension. The fibres must be removed by means of heat, which disperses and divides them; and after that the wire may again be reduced three numbers. The fibres which are re-produced by this operation are again removed by heat. The whole process is five times repeated; conse-

quently the wire is passed through fifteen numbers; after which, a single exposure to the fire is sufficient to fit it for passing six others, whereby it is reduced to the thickness of a knitting-needle.

The steel-wire, being much harder, requires to be passed through forty-four numbers, and to be annealed every other time.

The machine which draws the steel-wire must go slower than that which draws the iron; for the first being very hard, and offering more resistance to the drawing-plate, should be pulled out with more care, since the quickness ought to be proportioned to the resistance, and reciprocally; and if they depart from this principle, the results will vary. Thus, for example, the iron of the department de l'Orne, which is more compact than that produced at Haute Saone, if drawn by the same machines, augments in hardness, and is weakened when it is brought to too great a degree of fineness. But this iron, which is very hard, and capable of receiving a very high polish, is to be preferred for certain uses.

In order to anneal the wire, they formerly employed a large and elevated furnace, with bars of cast iron to support the wire in the middle of the flames. It contains seven thousand pounds weight, so contrived as to contain equal portions of each number. They are so arranged that the thickest wires receive the strongest heat; therefore, the whole is equally heated in the same space of time. The operation lasts three hours with a fire well kept up, and it might be imagined that this apparatus was completely adapted to the purpose; but there are imperfections in this method, because it leaves the wire exposed to the contact of the atmospheric air, the oxygen of which seizes it with extreme avidity; whence a considerable quantity of oxyd is occasioned, and also an operation to free it from the scales, which consists of beating the bundles of wire with a wooden hammer wetted with water.

Notwithstanding this precaution, there often remains a portion of oxyd adhering to the surface of the metal, which streaks the draw-plate, or fixes on the wire, and gives it a tarnished appearance, and causes it to break when it is brought to a great degree of fineness. This furnace is only used for the steel-wire, or the iron from l'Orne, which is less liable to change, and besides being harder is not so easily attacked by the oxygen.

In order to diminish the waste that the fire occasions, they have contrived another process, which consists in dipping the bundles of wire into a basin of wet clay before they put them into the furnace; and they are left in the furnace to dry before the fire is lighted, without which precaution the clay would peel off from the iron.

For making wire for cards, M. Mouchel invented another furnace. It is round, and about one metre six decimetres in diameter, and one metre eight decimetres in height, without including its parabolic arch and the chimney above it. The interior is divided by horizontal grates into three stories; the lowest receives the cinders, the second is the fire-place, and into the third or upper place they slide a rouleau of wire, weighing one hundred and fifty kilogrammes, which is inclosed in a space comprised between two cast-iron cylinders, being luted to prevent the admission of air between them. The flames circulate about the outside of the first, and within the interior of the second, which defends the wire from atmospheric air. The diameter of the largest cylinder is about one metre four decimetres, that of the second one metre. Thus the space comprised between them is two decimetres, on an elevation of five decimetres. There must be several pairs of cylinders provided; because whilst one

pair is in the furnace another must be prepared to receive a fresh rouleau of wire. They are changed every hour by means of a long iron lever, with which a single man can easily push them in and draw them out again, as the cylinder slides on cast-iron rails.

They are very careful not to open the cylinders immediately on their being drawn out of the fire; for the rouleaus of wire contained in them, being still red, would oxydate quite as much as if they had been heated in the midst of the flames without the least precaution.

The opening contrived for the passage is on the side, and has a door of cast iron, with a groove which winds round the furnace. The fire-place has one something similar to it. That of the ash-hole is vertical, in order that it may be raised to increase the fire at will.

When the iron-wire is reduced to the thickness of a knitting-needle, it is made up in bundles of 125 kilogrammes (275 pounds) each, into a large iron vessel, in order to anneal it sufficiently to be reduced for the last time. This vessel is placed upside-down in the middle of a round furnace, which is so constructed as to sustain burning coals all round it, and of which it consumes 35 kilogrammes (77 pounds) before the operation is completed. The cover must be carefully luted, as the slightest admission of air is sufficient to burn the external surfaces of the wire to an oxyd, which cannot afterwards be reduced.

When one of these vessels is sufficiently heated, it is filled with water, containing three kilogrammes (six pounds and a half) of tartar, and suspended over the flames of the furnace to make it boil. This solution, without attacking the metal, frees it from the grease and the little oxyd that adheres to it. This is the last operation in which the wire is exposed to the fire; and it is then in the proper state for being reduced to the utmost degree of fineness it is capable of sustaining, and will preserve enough of the effect of the annealing to require it no more. But when the natural hardness of the iron varies, this last exposure to the fire should take place in proportion to its thickness. As steel loses its capacity of extension much sooner than iron, it is annealed until it is no thicker than a sewing-needle. The space which is left in the vessel is filled up with charcoal-dust, which prevents it from losing the quality of steel, and preserves the heat long enough to give it the proper degree of pliancy.

As Messrs. Mouchel always use iron and steel of the same manufactory, they have been able to reduce their operations to a general system; and to attain this end, have determined a graduated scale, by which the wire will not be more stretched in the drawing-plate in one number or size than another. The following is the method they contrived, in order to form this scale for the iron-wire. They take a certain quantity of various thicknesses, which has been drawn as fine as the iron would bear. The smallest size is 100,000 metres (109,333 yards) in length to the kilogramme, 2.2 pounds avoirdupois. They note the weight that each might be capable of supporting without breaking. This being expressed by figures, it is easy, by a few interpolations, to express them in a progressive form. This kind of scale has been partly formed by comparing the weight of the different sizes with equal lengths, from which gauges or calibres may be made for the use of the workmen. These gauges are certain guides, which they cannot mistake except through great carelessness. If they had not these guides they would often pass the wire through holes in the drawing-plate that are too large for it, whence it does not acquire the strength it should have in proportion to its thickness, and loses its hardness. They might also pass it through holes

that were too small, which would weaken it, and render it very brittle. In the latter case, it frequently happens that the steel of the drawing-plate, being unable to sustain the force to which it is exposed, will give way, as if the plate were too soft; and the wire will be brittle at the beginning, and soft and too thick at the other extremity.

The greatest part of the fine wire of Messrs. Mouchel's manufactory is drawn by workmen who are dispersed about the country; but they have also a machine which moves twenty-four bobbins in a horizontal direction, which only requires the workman to look after it. It is upon the bobbins that the wire is reduced to the different degrees of thinness desired; therefore, this is the last operation in the art of making iron and steel wire; although it has all requisite qualities given to it in the work-shop of the wire-drawer.

Wire is still incapable of being made into needles and carding-hooks, until it has undergone another operation for dressing or straightening the wire, by which it is made to lose the bend or curve that it acquires on the bobbins.

This work consists in drawing the wire between nails fixed in a piece of wood, and which act to bend the wire, first in one direction, and then in the opposite, in a waving line, of which the waves are at first larger, but decrease gradually, and the last bend of which tends to force the wire into a straight line. The dresser is obliged constantly to adjust the nails, by inclining or raising them with strokes of the hammer. Also for each number of wires the pins must be at different and calculated distances. This requires a workman of intelligence, diligence, and address.

An ingenious instrument is now appropriated to this operation, and removes all difficulty. Six little puppets of very hard steel are substituted for the nails of the ordinary instrument, and are fixed on parallel bars of metal, so jointed together that the movement of them all will be parallel, and the puppets are widened or brought nearer together by screws. The wire is drawn between these puppets in a zigzag or waving line, and the repeated flexures break the sinuosities of the wire. There is a conductor of the wire to the puppets, and another conductor which serves to prevent the wire from being shaken. There are slight grooves at the extremity of the puppets, to give a passage to the wire. A scale sustained by a screw indicates the distance at which the puppets should be placed from each other, to straighten each size of wire. This forms an invariable rule, and the dresser (who may be a child) saves a third of the time which is employed in regulating the nails of the instrument formerly used. There is nothing more to be done but to draw out the wire by means of a wheel, on which he reels it, and then forms it into bundles to be delivered to the consumers.

The steel-wire of France is proper for many purposes. It is brought from Messrs. Mouchel, for making knitting-needles in the English fashion, shoemakers' needles, and other similar articles. It may also be used for needles of all sizes, and even for cards for wool-combing; but as this steel is much more expensive than the iron-wire, it is very seldom used for the latter purpose.

The method of preparing the draw-plates is described by Messrs. Mouchel, and is different from that before described.

For making wire for cards, two sorts of drawing-plates are used, large and small ones. The first, for the sort of wire that we have been describing, is drawn with the pincers, as *fig. 7*, and with the bobbin or roller, which is a cylinder adapted to the axis turned by the water-mill, and is used in preference, to avoid the marks made on the wire by the pincers. The small drawing-plates are used for such wire

as may be drawn by hand. The steel which they employ for these drawing-plates should never vary in quality, except that the smaller plates are made of the finest steel. Several pieces of iron are disposed in the furnace in the form of a box without a lid, their weight being according to the use for which they are intended to be employed.

The workman fills each of these boxes with cast steel, and having covered it over with a luting of clay, it is exposed to a fierce fire until the steel be melted. His art consists in seizing the proper moment to withdraw the plate from the fire: he raises the luting, and blows on it through a tube, in order to drive off all heterogeneous parts, and then amalgamates it with the iron by light blows. After it is cool, he replaces it at the fire, where the fusion again takes place, but to a less degree than before; he afterwards works the steel with light blows of the hammer, to purify and solder it with the iron. This operation is repeated from seven to ten times, according to its quality, which renders it more or less difficult to manage. During this process, a crust forms on the steel, which is detached from it the fifth time of its exposure to the fire, because this crust is composed of an oxydated steel of an inferior quality. It sometimes happens that two and even three of these crusts are formed of about two millimetres, or one-sixteenth of an inch in thickness, which must also be removed.

After all these different fusions, the plate is beaten by a hammer wetted with water, and the proper length, breadth, and thickness, are given to it. When thus prepared, the plates are heated again, in order to be pierced with holes by punches of a conical form; the operation is repeated five or six times, and the punches used each time are progressively smaller. It is of importance that the plate never be heated beyond a cherry-red, because if it receives a higher degree of heat, the steel undergoes an unfavourable change. The plates, when finished, present a very hard material, which nevertheless will yield to the strokes of the punches and the hammer, which they require when the holes become too much enlarged by the frequent passing of the wire through them.

When the plates have been repaired several times, they acquire a degree of hardness, which renders it necessary to anneal them, especially when they pass from one size to another; sometimes they do not acquire the proper quality until they have been annealed several times. Notwithstanding all the precautions which are taken in preparing the plates, the steel still varies a little in hardness, and according to this variation they should be employed for drawing either steel or iron wire; and if the workman who proves them finds that they are too soft for either the steel or iron, they are put aside, to be used by the brass-wire drawers.

A plate that is best adapted for drawing steel-wire is often unfit for the iron; for the long pieces of this latter metal will become smaller at the extremity than at the beginning, because the wire as it is drawn through the plate is insensibly heated, and the adhering parts are swelled, consequently pressed and reduced in size towards the latter end. The plates that are fit for brass are often too soft for iron, and the effect resulting is the reverse of that produced by a plate that is too hard.

The smallest plates which Messrs. Mouchel use are at the least two centimetres, or eight-tenths of an inch in thickness, so that the holes can be made sufficiently deep; for when they are of a less thickness, they will seize the wire too suddenly and injure it. This inconvenience is much felt in manufactories where they continue to use the plates for too long a time, as they become exceedingly thin after frequent repairs. One of Messrs. Mouchel's large plates

reduces 1400 kilogrammes (3080 pounds *avoirdupois*) from the largest size of wire to No. 6, which is of the thickness of a knitting-needle; 400 kilogrammes (880 pounds) of this number are afterwards reduced in one single small plate to No. 24, which is carding wire; and to finish them, they are passed through twelve times successively.

For the tenacity of iron wire, see IRON.

The first wire-mill in England was set up by a Dutchman at Sheen, near Richmond, in 1663.

Wires are frequently drawn so fine, as to be wrought along with other threads of silk, wool, or hemp; and thus they become a considerable article in the manufactures. See DUCTILITY.

WIRE, Gold. See GOLD-WIRE.

Muschenbroeck records, that an artist of Augsburg drew a wire of gold so slender, that 500 feet of it weighed only one grain; and Dr. Wollaston, secretary of the Royal Society, has shewn, that a wire of gold may be drawn much finer than this, and that wires of platina may be drawn much more slender, with the utmost facility. Those who draw silver-wire in large quantities for lace and embroidery, sometimes begin with a rod that is about three inches in diameter, and

ultimately obtain wires that are so small as $\frac{1}{100}$ of an inch in

thickness. If in any stage of this process a rod of silver-wire be taken, and a hole be drilled through it longitudinally, having its diameter one-tenth part of that of the rod, and if a wire of pure gold be inserted, so as to fill the hole, it is evident that by continuing to draw the rod, the gold within it will be reduced in diameter exactly in the same proportion as the silver; so that if both be thus drawn out

together till the diameter of the silver is $\frac{1}{500}$ of an inch, then

that of the gold will be only $\frac{1}{5000}$; and of such wire, 550

feet would be requisite to weigh one grain. In order to remove the coating of silver that surrounds it, the wire must be steeped for a few minutes in warm nitrous acid, which dissolves the silver without any injury to the gold. Dr. W., in his endeavours to make slender gold-wires by the method above-described, found it difficult to drill the central hole in a metal so fine as silver, and therefore tried whether platina might not be substituted for the gold, as in that case its infusibility would allow its being coated with silver, without the necessity of drilling. Having formed a cylindrical mould one-third of an inch in diameter, he fixed in the centre

of it a platina wire previously drawn to the $\frac{1}{100}$ of an inch,

and then filled the mould with silver. When this rod was

drawn to $\frac{1}{30}$, his platina was reduced to $\frac{1}{1000}$, and by suc-

cessive reduction he obtained wires of $\frac{1}{4000}$ and $\frac{1}{5000}$, and

excellent for applying to the eye-pieces of astronomical instruments, and perhaps as fine as can be useful for such purposes. The extremity of a platina wire having been fused into a globule near $\frac{1}{4}$ of an inch in diameter, was next hammered out into a square rod, and then drawn again into a

wire $\frac{1}{253}$ of an inch in diameter. The fusion was effected

by the following simple and easy method suggested by Dr.

Marcet:—A piece of wire, about six inches long, having been bent to an angle in the middle, one half of its length was held in the flame of a spirit-lamp impelled by a current of oxygen, and its extremity was thus fused in about half a minute. An inch of the wire above-mentioned duly coated with silver was drawn, till its length was extended to 182 inches; consequently the proportional diminution of the diameter of the platina will be expressed by the square root of 182, so that its measure had become

$$\frac{1}{253 \times 13.5} = \frac{1}{3425}$$

The specific gravity of the coated wire was assumed to be 10.5, and since the weight of 100 inches was 114 grains, its diameter was inferred to be

$$\frac{1}{42.8} \text{ of an inch, and just eighty times of the platina thus}$$

contained in it. With portions of the platina wire thus obtained, and successively reduced in diameter, its tenacity was ascertained; and the results of several trials shewed in general, that the process of wire-drawing, which is known to improve the strength of metals within moderate limits, continued also to add something to the tenacity of platina,

even as far as $\frac{1}{18.000}$ of an inch, which supported $1\frac{1}{2}$ grain

before it broke; but the wire in which the experiments were made began then to be impaired by repetition of the operation; so that although he afterwards obtained portions

of it as small as $\frac{1}{30.000}$ of an inch in diameter, it was in

many places interrupted, and he could not rely on any trials of its tenacity. For other particulars with regard to these fine wires, we refer to the *Phil. Trans.* vol. ciii. pt. 1.

WIRE, Silver, is the same with gold wire, except that the latter is gilt, or covered with gold, and the other is not. There are also counterfeit gold and silver wires: the first made of a cylinder of copper, silvered over, then covered with gold; and the second of a like cylinder of copper silvered over, and drawn through the iron, after the same manner as gold and silver wire.

By 43 Geo. III. c. 68. several duties are imposed on wire imported, as set forth in tables annexed to the act; and by c. 69. sched. A. duties are laid upon wire made in Great Britain; and by 49 Geo. III. c. 98. new duties are imposed. Every wire-drawer who shall draw any gilt or silver wire, commonly called 'big wire,' shall take out a

licence, for which he shall pay 2*l.*, to be renewed annually on pain of 20*l.* 24 Geo. III. c. 41. One licence suffices for a partnership. Notice is to be given of working on pain of 20*l.*, and the place of working is to be approved by the commissioners under the same penalty. Wire, and bars for making it, and utensils, found in any private workhouse, of which no notice hath been given, shall be forfeited. Officers shall be permitted to enter and survey, and the penalty of obstructing him is 20*l.* 10 Ann. c. 26. Preventing him from taking a just account incurs a forfeiture of 100*l.* 26 Geo. III. c. 77. Just scales and weights shall be kept on pain of 10*l.* Persons using false scales and weights forfeit 100*l.* 10 Geo. III. c. 44. And the same shall be forfeited and seized. 28 Geo. III. c. 37. Ingots or bars of silver, designed for gilt wire, shall be weighed in the presence of the excise officer, before they be covered with gold, and again weighed and marked after the gold is laid on, under penalty of 20*l.* 15 Geo. II. c. 20.

By 10 Ann. c. 26. an allowance of one-fifth is made for waste in reducing the big wire to small wire. Removing wire before it is surveyed incurs a penalty of 40*l.*; and unsurveyed wire is to be kept separate, on pain of 10*l.*; and the punishment of concealing wire, &c. is a forfeiture of 20*l.* The wire made shall be entered every month, on oath, on pain of 100*l.* The duty must be cleared off in six weeks after entry, on pain of double duty.

By 15 Geo. II. c. 20. and 22 Geo. II. c. 36. no foreign embroidery, or gold or silver brocade, thread, lace, fringe, or work made thereof, or of copper, brass, or other inferior metal, or gold or silver wire, or plate, shall be imported. And by 10 Ann. c. 26. if any person shall export any gold or silver thread, or lace or fringe made of plate wire spun upon silk, he shall have a drawback after the rate of 5*s.* a pound avoirdupois, of such silver thread, lace, or fringe, and of 6*s.* 8*d.* a pound of such gold thread, lace, or fringe.

For regulations concerning the true making of gilt and silver wire, see the statute 15 Geo. II. c. 20. and for prohibiting the selling or working up of foreign gold or silver lace or thread, see 22 Geo. II. c. 36.

WIRE, Brass, is drawn after the same manner as the former. Of this there are divers sizes, suited to the divers kinds of works. The finest is used for the strings of musical instruments, as spinets, harpsichords, manichords, &c.

The pin-makers likewise use vast quantities of wire of several sizes, to make their pins of. See **PIN**.

WIRE, Iron. See **WIRE** *supra*.

Fig 2



Fig 13

Fig 3

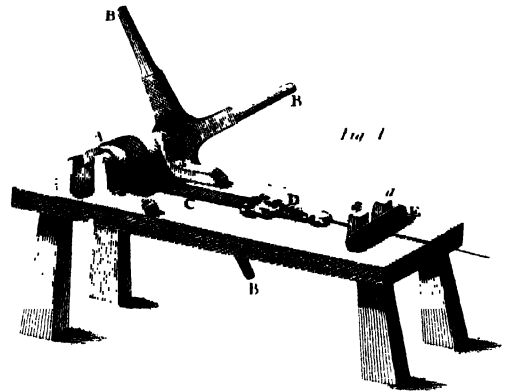


Fig 4



Fig 12

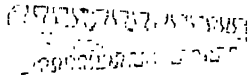


Fig 11

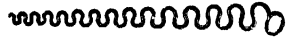


Fig 5

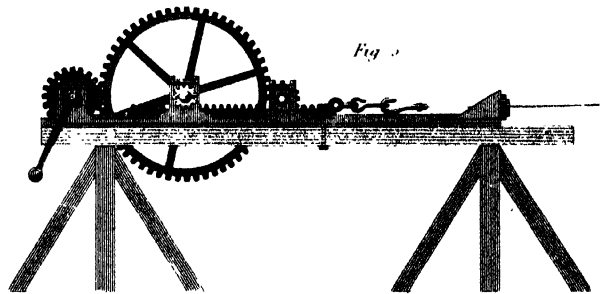


Fig 8

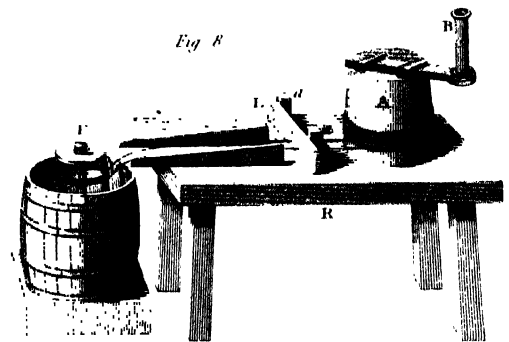


Fig 9

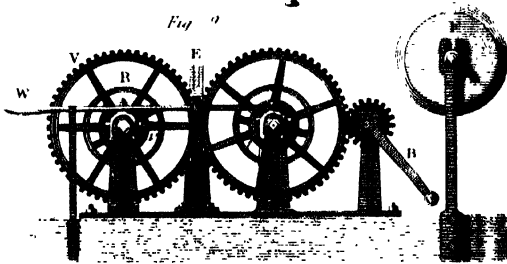


Fig 10

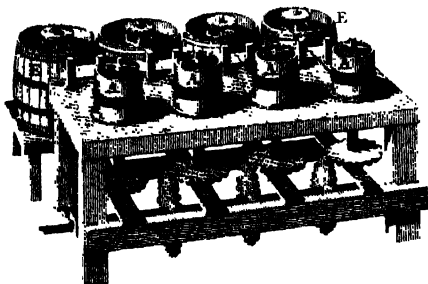
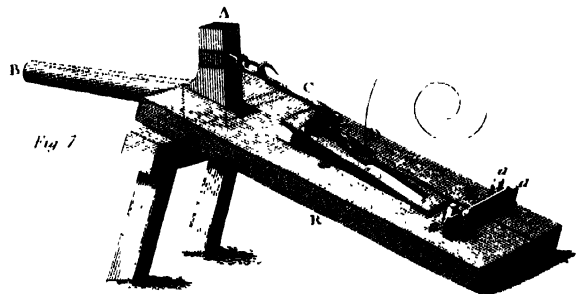


Fig 7



Woad

WOAD, in *Agriculture*, a plant cultivated in the field for the use of the dyers. It is a plant which has a strong thickish fibrous root, which penetrates deep into the soil, and which is principally raised for the use of the leaves, which, after being properly manufactured, are made use of in the art of dyeing to produce a blue colour, as well as the basis of black, and some others.

Soil.—It is evident from the nature of its root that it requires a soil which has much depth or staple, and which is perfectly fresh, such as those of the rich, mellow, loamy, and deep vegetable kind. Where this sort of culture is carried to a considerable degree of perfection, as in Lincolnshire, the deep, rich, putrid, alluvial soils on the flat tracts extending upon the borders of the different large rivers are chiefly employed for the growth of this sort of crop; and it has been shewn by repeated trials that it answers most perfectly when they are broken up from a state of sward immediately for it. In some places, it is the practice to take lands of this description at high prices, for the purpose of breaking them up and growing it upon them for two or three years; on the more low rich soils, for four years, but on those of less fertility only for three; and in some, which are more elevated and exposed, two are considered sufficient. For this sort of culture, people are employed, who move from place to place, and form a sort of colony. Mr. Cart-

wright, in the above county, has however found, that it is capable of being confined to one spot with equal or greater success, by having a sufficient extent of ground for changing the place of its growth as may be necessary, and for appropriating an adequate proportion annually to the raising of the plant, by which the houses and expensive machinery that are necessary for its preparation may be kept constantly and regularly employed in the business.

Preparation.—In order to prepare the land for this crop, it is advised by some to plough it up with a good deep furrow, immediately before the winter commences, laying it in high narrow ridges, to have the full effect of the frosts; and early in the spring to give another ploughing in the contrary direction, leaving the ground in the same kind of ridge as before. When it has remained in this state some length of time, and weeds appear, it should be well harrowed down with a heavy harrow, repeating the operation so as to render it perfectly fine and clean. About the beginning of June a third ploughing should be given to the full depth with a narrow furrow, and the land be afterwards well harrowed down as before; the fourth or final ploughing being given towards the beginning of July, in a light manner, leaving the surface as even as possible for the seed. But some take much less trouble in the business of prepara-

tion. In cases where the soils are sufficiently dry, only breaking them up early in the month of February; and where the contrary is the case, deferring it to a later period, taking care to plough the land in a perfect manner to the depth of five inches, or more: and that the furrow-slices may be well turned, laid flat, and nicely jointed, a person is employed with a spade for the purpose of adjusting them. This prevents the grassy matters from rising in the seams. When this has been done, the surface is repeatedly harrowed over, to raise a sufficient depth of good mould for the drill to work in; and before the seed is put in a roller is passed over the land.

It is probable, however, that this method is inferior to the former, as the land is not brought nearly to so fine a state of mould, or the grassy material so effectually covered and destroyed, from which injury may be done to the woad plants in their early growth.

But a method which is equally effectual with the first, more expeditious, and which has a superiority over it, in more completely destroying grubs, insects, and other vermin, which are apt to feed on the plants in their early growth, is that of paring and burning. This is, however, chiefly practised where the sward is rough, and abounds with rushes, sedge, and other plants of the coarse kind, but might be had recourse to on others, with vast benefit.

Where the latter modes are made use of as soon as the seed has been put in, the land should be carefully drained by forming grips in suitable directions, as wherever water stagnates, the woad plants are liable to be injured or destroyed.

Seed.—In respect to the seed, it should be collected from ground that has been left covered with the best plants from the preceding season, as they only run up to stem and form seeds in the second year; and in order to have good seed, the leaves should not be cropped at all or but once, the stems being suffered to remain till the seeds in the husks become perfectly ripened; which is shewn by their attaining a brownish-yellow colour, and the pods having a dark blackish appearance. It should then be gathered as soon as possible, by reaping the stems in the manner of grain, and then spreading them in rows thinly upon the ground if the weather be fine, when in the course of a few days they will be in a state to be threshed out from the husks or pods. When they are suffered to remain too long, the pods are liable to open, and shed the seed. Although the pods in which the seeds are contained is of a large size, the seeds are less than those of the turnip. New seed, where it can be procured, should always be sown in preference to such as has been kept for some time; but when of the latter kind, it should be steeped for some time before it is put into the ground.

In regard to the quantity of seed which is necessary, it must be regulated by the soil, and the manner in which it is sown. Where the drill is employed, less will be required than in the broad-cast method. It has been found that a rood of land, where the crop is good, will in general afford seed sufficient for eight or ten acres; and in some cases, in the broad-cast method, five or six bushels are made use of to the acre. In Kent they use ten or twelve pounds to the acre.

Sowing.—The time of sowing crops of this nature must be regulated, in some degree, by the mode of preparation that has been employed. Where the first of the above methods has been followed, it will be much later than in the other cases. But early sowing is in general to be preferred, as there will be less danger of the plants being injured by the attacks of the fly or grub. Where the weather is suitable, and the land in a proper state of preparation, the

seed may be sown in the latter end of February or March, continuing the sowings, in different portions of land, till about the middle of May, at suitable intervals of time to vary the times of cropping the leaves of the plants. The late sowings are commonly executed about the latter end of July, or early in the following month at the farthest.

With respect to the manner in which the seed is sown, it differs according to the nature and state of preparation of the land. Where it is in a fine state of mould, the drill or row method is the method mostly practised, which is by much the best, as by it the plants may be kept more easily clean and free from weeds, becoming more strong and vigorous, from the earth being more stirred about the plants: but where the contrary is the case, the broad-cast mode is generally followed; but which does not by any means admit of the plants being kept so free from weeds, or the mould so well stirred about the roots of them.

Where the first method is had recourse to, the seed is sown by a drilling-machine, such as is used for turnips, in equidistant rows, eight or nine inches apart, covering it in, either by means of a harrow attached to the implement, or by passing a light common harrow over the ground afterwards, once in a place, raking off any clods that may be present to the sides, or into the furrows: but in the latter mode, it must be dispersed by the hand in as equal a manner as possible, over the whole of the land, being then harrowed in by a light harrow, so as to leave the land in as even and level a state as possible. The ground is frequently rolled afterwards, that the surface may be left as even as possible.

In favourable seasons with good seed, the plants mostly appear in the course of a fortnight, when much attention should be paid to see that they are not destroyed by the turnip-fly, or the frosts in those of the more early sowings; as, where that is the case, the land should be immediately resown; as in some cases it is not uncommon to sow the greatest part of the crop two or three times over. In the very late sowings, where the crops rise thin on the ground, it is sometimes a practice to give a better plant by forming holes with a hoe in the vacant spots, and directing seeds to be dropped into them by the hand by women or children. This is the case with the late spring-sowings till the beginning of June, or a later period.

Culture while growing.—From much of the goodness of the woad plants depending on the luxuriance of their growth, and the thickness of their leaves, it is necessary to bestow great attention in the culture of the crop while growing. It is advised that the spring-sown crops, as well as those that are sown in the latter part of the summer, should have the first hoeings given them as soon as the plants are fully distinguishable above the ground, as by this means the weeds will not only be prevented from retarding the vegetation of the plants, but these by being thinned out to greater distances be more at liberty to advance and become vigorous in their first or early growth, which is a matter of much consequence to the success of the crop; and second hoeings should be given in the course of four or five weeks afterwards, when the plants should be thinned out to the full distances at which they are to stand, which may be six or seven inches, or more, according to the goodness of the soil, constantly leaving sufficient room to prevent the plants from being in any way crowded. The work is sometimes executed in much the same manner as for turnips, by hand-hoes; but in others by small short spuds, used with one hand, while the other is employed in clearing away the weeds; the labourers, mostly women and children, kneeling while they perform the work. When this work has been done, nothing further is necessary till the first cropping of

the leaves has been performed, when the plants should be again immediately well weeded; and after each cropping the same operation be had recourse to; the extent of crop cleared in the day being, in most cases, weeded before night.

With the late-sown crops, after the second weeding in October, nothing further will be requisite till the spring, about the middle of April, when the work should be again well executed, the mould being completely stirred about the roots of the plants, that they may derive the fullest benefit from the operation. This will be sufficient to keep them clean till the taking of the first crop; after which they must be again weeded, and the same operation be had recourse to after each cropping of the leaves, as in the above case.

In respect to the business of gathering the crops with the spring-sown ones, the leaves will generally be ready to be gathered towards the latter end of June, or beginning of July, according to the nature of the soil, season, and climate; but for those put in at a later period in the summer, they are often fit to be gathered earlier. This business should, however, constantly be executed as soon as the leaves are fully grown, while they retain their perfect green colour, and are highly succulent; as when they are left to remain till they begin to turn pale, much of their goodness is said to be expended, and they become less in quantity, and of an inferior quality for the purposes of the dyer. In favourable seasons, where the soils are rich, the plants will often rise to the height of eight or ten inches; but in other circumstances they seldom attain more than four or five: and where the lands are well managed in the culture of the plants, they will often afford two or three gatherings, but the best cultivators seldom take more than two, which are sometimes mixed together in the manufacturing of them. It is necessary that the after-croppings, when they are taken, are constantly kept separate from the others, as they would injure the whole if blended together, and considerably diminish the value of the produce. It is said that the best method, where a third cropping is either wholly or partially made, is to keep it separate, forming it into an inferior kind of woad.

Upon an acre of land, when well managed, in favourable seasons, the produce is mostly from about a ton to a ton and a half. The price varies considerably; but for woad of the prime quality, it is often from twenty-five to thirty pounds the ton, and for that of an inferior quality six or seven, and sometimes much more.

Seeding-Crops.—With such parts of the crops as are reserved for seed, it is a practice with some to crop the leaves two or three times the first year, and then leave the plants to run up to seed in the following one; but it is a better practice to only remove the side-leaves, as in this way the plants are less weakened, and the produce of the seed much increased. The plants are likewise sometimes fed down by sheep during the winter season; but this, from its tendency to weaken them, is equally improper and prejudicial.

Preparation of for the Dyer.—The woad, after it has been gathered, undergoes several processes to prepare it for the dyer; but in the improved method it is conveyed in one-horse carts, so contrived as to be lifted from the axis, and, by folding doors in the bottoms, to discharge their contents upon the floor above the mill, on being hoisted up to their proper situation: round this floor holes are formed for putting the plants down through, in order that they may drop under the grinding-wheels. The mills for this purpose have several wheels for grinding the plants, which have less diameters on one side than the other, and are about three feet in width, being constructed with iron bars for

crushing the woad. They are wrought by horses, or any other power, as may be the most convenient. The materials are preserved under the grinding-wheels by proper contrivances, which, as soon as they are sufficiently reduced, force it out of the tracks upon the stone floors on the sides; thus making way for new parcels without the mill being stopped. The bruised woad is then thrown into rooms on the sides of the mill, destined for its reception, by means of shovels. In these it remains till the juice is so much drained off as to leave it in a proper condition for being formed into balls; which is done by labourers, with apparatus for the purpose, and then laid upon trays to be conveyed to the drying ranges, in which they are placed upon grating-shelves that slide on sledges in the drying-houses. These are placed on the sides of galleries, for the convenience of being easily deposited upon them and removed again. It is kept in these till it is sufficiently dried to be laid up in other rooms, until the whole of the crop has undergone the same operations, and the workmen are ready to manufacture it.

It is stated in the Corrected Lincolnshire Report on Agriculture, that to prepare it for use in the art of dyeing, it is necessary for it to take on a proper state of fermentation, which is accomplished in the course of seven or eight weeks, and, in the technical language of the art, is termed *couching*. It is effected by regrinding the balls, in the same mill as before, to a fine powder, and then spreading it upon the floors of the rooms in which the balls were formed, to the thickness of about three feet; where it is then moistened with water, so as to keep it in a proper flow state of fermentation; and so managed by turning that it may pervade the whole in an equal manner. In this business, the direction of an experienced workman is necessary. In the turning, it is of much importance that the parts of the materials be perfectly divided, which can only be effected by a nice management of the shovel: and it is added that much advantage has been found in the goodness of the woad, from the drying and storing of it being performed in a careful manner. When this attention is neglected, the woad will not, on being broken between the finger and thumb, draw out into fine hair-like filaments, or, in the technical language of the manufacturer, *beaver* well; as the use of this substance in the blue vat of the dyer, is not merely to afford the colour of the plant, but, by bringing on a very gentle fermentation, excite the indigo in the same vat to yield its colouring principle more perfectly. This is even necessary for its own colouring-matter being fully imparted. The substance should, therefore, be so prepared in the different operations as to produce this effect in the most certain and perfect manner. When the heat in the process of couching has gone too far, the substance will be what is termed *foxy*; and when it has not proceeded to a sufficient degree, it will be what is called *heavy*. If the material be good, it does not soil the fingers on being rubbed between them; but such as is heavy does. In the conclusion of the process, the cooling is effected in so gradual a manner, as to render it not fit for taking on the same process; and of course proper for being preserved in casks, or in any other way. It is then ready for use.

The preparation of woad for dyeing, as practised in France, is minutely described by Astruc, in his *Memoirs for a Natural History of Languedoc*. The plant puts forth at first five or six upright leaves, about a foot long, and six inches broad: when these hang downwards, and turn yellow, they are fit for gathering: five crops are gathered in one year. The leaves are carried directly to a mill, much resembling the oil or tan-mills, and ground into a smooth paste. If this process was deferred for some time,

they would putrefy, and send forth an insupportable stench. The paste is laid in heaps, pressed close and smooth, and the blackish crust, which forms on the outside, reunited if it happens to crack: if this was neglected, little worms would be produced in the cracks, and the woad would lose a part of its strength. After lying for fifteen days, the heaps are opened, the crust rubbed and mixed with the inside, and the matter formed into oval balls, which are pressed close and solid in wooden moulds. These are dried upon hurdles: in the sun, they turn black on the outside; in a close place, yellowish, especially if the weather be rainy: the dealers in this commodity prefer the first, though it is said the workmen find no inconsiderable difference betwixt the two. The good balls are distinguished by their being weighty, of an agreeable smell, and when rubbed of a violet colour within. For the use of the dyer, these balls require a farther preparation: they are beat with wooden mallets, on a brick or stone floor, into a gross powder; which is heaped up in the middle of the room to the height of four feet, a space being left for passing round the sides. The powder, moistened with water, ferments, grows hot, and throws out a thick fetid fume. It is shovelled backwards and forwards, and moistened every day for twelve days; after which it is stirred less frequently, without watering, and at length made into a heap for the dyer.

The powder thus prepared gives only brownish tinctures, of different shades, to water, to rectified spirit of wine, to volatile alkaline spirits, and to fixed alkaline lixivium: rubbed on paper, it communicates a green stain. On diluting the powder with boiling water, and after standing some hours in a close vessel, adding about one-twentieth part of its weight of lime newly slacked, digesting in a gentle warmth, and stirring the whole together every three or four hours, a new fermentation begins, a blue froth arises to the surface, and the liquor, though it appears itself of a reddish colour, dyes woollen of a green, which, like the green from indigo, changes in the air to a blue. This is one of the nicest processes in the art of dyeing, and does not well succeed in the way of a small experiment.

Astruc proposes the manufacturing of fresh woad leaves in Europe, after the same manner as the indigo plant is manufactured in America; and thus preparing from it a blue secula similar to indigo, which from his own experiments he has found to be practicable. Such a management would doubtless be accompanied with some advantages, though possibly woad so prepared might lose those qualities which now render it, in a large business, preferable on some ac-

counts to indigo, as occasioning greater dispatch when once the vat is ready, and giving out its colour less hastily, so as to be better fitted for dyeing very light shades. Neumann's Chem. by Lewis, p. 437, &c.

The ancient Gauls and Britons used to dye or stain their bodies with this plant, and were probably led from this application of it to use it for dyeing cloth.

Some hold that it was from this plant glass took its denomination; though others derive both *glass* and *glastum* from the British *glass*, which to this day denotes a blue colour. See GLASS.

A woad blue is a very deep blue, almost black; and is the base of so many sorts of colours, that the dyers have a scale, by which they compose the divers casts or degrees of woad, from the brightest to the deepest.

WOAD, in Botany. (See ISATIS.) There are four species.

The broad-leaved woad is cultivated in several parts of England for the purposes of dyeing, being used as a foundation for many of the dark colours.

Some feed down the leaves of woad in winter with sheep; a practice which Mr. Miller condemns.

Woad grows wild in some parts of France, and on the coasts of the Baltic sea: the wild woad, and that which is cultivated for the use of dyers, appear to be of the same species.

Beside the plant properly signified by the name woad, which dyes a blue colour, we have two others known in our English herbals under that name, as also that of *wold* or *weld*. These are both called by the common people *dyer's weed*, and are the *luteola* and the *genista tinctoria*.

The ancients confounded all these three plants also under the same names. Paulus Ægineta seems to make them all the same plant; and Neophytus, speaking of the *isatis*, or our woad, properly so called, says, that it was called by the Latins *lutum*. This *lutum* has been by some understood to mean the *luteola*, and by others the *genista tinctoria*; but the latter opinion only is right, for it is described to us by the ancients as having leaves like the *linum*, or flax, and flowers like the broom.

WOAD-Mill and House, that sort of mill and house which is necessary and proper for preparing and fitting this kind of substance for the use of the dyer. The representation of a mill and excellent apparatus for effecting the preparation of the woad plant, which is made use of by Mr. Cartwright, with much success and advantage, in Lincolnshire, may be seen in the second volume of the "General Dictionary of Agriculture and Husbandry."

Wool

WOOL, in *Natural History* and *Manufactures*, Latin *lana*, *lanicium*, Fr. *laine*, signifies soft hair or down, more particularly that of sheep, but is applied to the soft hair of other animals, as of the vicunna, commonly called Vigonia wool, that of the yak of Tartary, &c.; and also to fine vegetable fibres, as cotton. The Romans applied the term extensively to the soft hair or down of all quadrupeds, and even to that of birds, as *lana anserina*, the wool or down of the goose; *lana caprina*, goat's-wool.

They also applied the term to vegetable substances:

——“*Nemora Æthiopium molli canentia lana.*”

Virg. Georg. ii. 120.

“The trees of Ethiopia, white with soft wool, or cotton.” The distinction between wool and hair is rather arbitrary than natural, consisting in the greater or lesser degrees of fineness, softness, and pliability of the fibres. When they possess these properties so far as to admit of their being spun and woven into a texture sufficiently pliable to be used as an article of dress, they are called wool. The gradations between wool and hair on the skins of some animals are often too minute to admit of accurate distinction. The fleeces of many sheep contain fibres so hard and coarse, that they may most properly be called hair; and some hairy animals produce on part of their skins fibres possessing all the properties of wool; even in fleeces from the sheep, we may sometimes observe the very same fibre to be a coarse hair at one end, and at the other end a comparatively soft wool. The power of words, when inaccurately applied in retarding the progress of improvement, may frequently be traced in the most common occurrences of life, and we are persuaded it has had no inconsiderable effect in this instance, in preventing the cultivation of wool, in Europe, on the skins of other animals besides sheep. No one will deny that it is impossible to produce wool on the backs of the ox or the ass, if we restrict the term wool to the fleece of the sheep; but if by wool we mean a soft fine hair, possessing all the properties which render it suitable to be spun, woven, and fulled, to make cloth, the oxen of Thibet and the asses of Chili do produce and have for centuries produced such wool. Many of the asses and oxen even in this kingdom have soft woolly

tufts of hair on some parts of their skins, and if such cattle were selected, and the breed cultivated, it is probable we might obtain from them a valuable addition to the materials on which national industry might be profitably employed.

Sheep's-wool appears to be the product of cultivation; we know of no wild animal which resembles the wool-bearing sheep. The argali, from which all the varieties of sheep are supposed to be derived, is covered with short hair, at the bottom of which, close to the skin, there is a softer hair, or down. (See ARGALI and SHEEP.) This is not peculiar to the argali; almost all quadrupeds inhabiting cold climates are covered in the same manner with a soft hair or down, which is protected by a coat of longer and coarser hair. By removal to a temperate climate, or when placed under the fostering care of man, and protected from the inclemencies of the weather, and supplied regularly with food, the coarse long hair falls off, and the animal retains only the softer and shorter hair, or wool. It is also observed that European sheep, removed to tropical climates and much exposed, soon become languid and sickly, and lose their fleece, which is succeeded by a covering of short coarse hair. Sheep in exposed situations in Europe often produce short coarse white hairs called kemps, intermixed with the finer wool; on removal to a warmer situation, and to a richer pasture, the coarse hairs fall off, and do not grow again. These facts are sufficient to prove the effect of cultivation on the fleece; and it must be observed that sheep's-wool of a good quality is never found but in those countries which have been the seats of the arts, and where a considerable degree of luxury or refinement exists, or has once prevailed. This is a strong presumptive proof that such wool has been originally obtained by a careful and long-continued attention to the selection of those sheep which produced the finest and most valued fleeces.

Angora, the ancient Ancyra, the former seat of arts and manufactures, still retains its breed of fine-woolled animals, among which the goat at the present time produces a fleece nearly equal to silk in lustre and fineness; and the cat and the rabbit of that district yet produce fine long wool. Damascus, and the other ancient cities of Asia Minor, preserve

in their vicinity the traces of the former cultivation of fine-woolled animals. The Tarentine fine-woolled sheep, so much valued by the Greeks and Romans, were obtained from Asia Minor, and were on that account sometimes called *Asiæ*. It is highly probable that these sheep came originally from the more eastern seats of luxury, where the soft fleeces are now grown, of which the shawls and cloths of India are fabricated.

In countries where manufactures have once flourished, their effects continue for a long time visible in the race of sheep which still remain there. Even in the present condition of the fleeces from Barbary and the adjoining states, the experienced eye may perceive the vestiges of a fine-woolled race of sheep, degenerated by utter neglect, in a climate naturally unfavourable to the production of fine wool. In Sicily and the southern parts of Italy, the remains of the ancient Tarentine breed preserve to the present day a race of fine-woolled sheep, but greatly degenerated by neglect. In Portugal the fine-woolled sheep retain more of their original purity, but are still much neglected. In Spain attention to the growth of fine wool appears never to have been entirely lost sight of, and it is here that the race of fine-woolled sheep exist in the highest degree of perfection, though, as we shall afterwards state, probably inferior in some important qualities to the original Tarentine race. Some writers have asserted that fine wool is the result of climate and food; but this is not the fact, though we admit that both have some influence on the quality of wool. It is the breed alone that primarily determines the fineness of the fleece; this has been ably demonstrated by the experiments of lord Sommersville, Dr. Parry of Bath, and others in this country, and by experiments on a larger scale in Sweden, Denmark, Saxony, and France.

It has been ascertained by Mr. Bakewell of Dishley, in Leicestershire, that the form of animals might be changed by selecting such as had any remarkable peculiarities, and continuing to breed from them for a few generations, when a new race is established, in which these peculiarities continue permanent. It has been ascertained by careful observations, both of cattle-breeders and physiologists, that in producing a new breed from two varieties of the same species, the female has more influence over the form of the progeny than the male; but with respect to wool the case is reversed, the quality of the fleece depending more on the sire than the dam. Beginning to breed from a coarse-woolled ewe and a pure fine-woolled ram, the produce of the first cross will have a fleece approaching one-half to the fineness of that of the ram; and continuing to cross this progeny with a fine-woolled ram, equal to the first in quality, the fleece of the score and cross will approach three-fourths to the fineness of the first, and in a few crosses more will be brought to an equal quality. If we state it numerically, and suppose the wool of the ewe to be twice as coarse as that of the ram, or as 320 to 160, the first cross will have the fibre reduced to 240, the second to 200, the third to 180, the fourth to 170, the fifth to 165, the sixth to 162½, which to all practical purposes may be regarded as equal to the first number. This ratio of approximation may be stated as correct on a large scale of experiment. If we breed with a fine-woolled ewe and a coarse-woolled ram, the series would be reversed, and in a few generations all vestiges of the fine-woolled race would be nearly, if not entirely, extinct. The ancient Romans, in the time of Columella, seem to have been fully aware of the effects of breed on the fineness of the wool, and as much as 200*l.* sterling was paid for a fine-woolled ram.

When a flock of fine-woolled sheep are once formed, they can only be kept pure by selecting and preserving the

finest-woolled rams, and most carefully avoiding all intermixture with sheep from coarser-woolled flocks that may exist in the country. Where this is neglected, the quality of the wool will soon be debased.

But supposing all the flocks in a country were of the fine-woolled race, accidental varieties of coarse-woolled sheep will occur among them, or of sheep having fleeces intermixed with coarse hair. If these be not carefully examined and removed, the wool will deteriorate, and more so where the climate is variable, and the sheep are exposed to great and sudden vicissitudes of temperature.

What has been stated may suffice to explain the circumstance of fine-woolled breeds of sheep being only found in the vicinity of present or ancient manufactures, or where they have been transported from such districts. Wherever fine-woolled sheep are neglected by man, the wool becomes either coarse, or intermixed with coarse hairs; the latter is the case in the Shetland isles, and in all countries where the arts and manufactures have been entirely destroyed, and ignorant barbarians have succeeded as the possessors of the soil.

Most ancient writers on wool, and even many moderns, seem not to be aware of any difference in wools, except the fineness or coarseness of the fibre; but the length of the fibre constitutes a far more important distinctive character. Long wool, or what is called *combing-wool*, differs more from short or clothing wool, in the uses to which it is applied, and the mode of manufacture, than flax from cotton.

Sheep's-wool may, therefore, be divided into two kinds. Short wool, or clothing-wool, and long or combing wool: each of these kinds may be subdivided into a variety of sorts, according to their degrees of fineness. This process is the proper labour of the wool-sorter.

Short wool, or clothing-wool, may vary in length from one to three or four inches; if it be longer it requires to be cut or broken, to prepare it for the further processes of the cloth manufacture. Short or clothing wool is always carded or broken upon an instrument with fine short teeth, by which the fibres are opened and spread in every direction, and the fabrics made from it are subjected to the process of felting, which we shall afterwards describe. By this process, the fibres become matted together, and the texture rendered more compact.

Long or combing wool may vary in length from three to eight or ten inches: it is prepared on a comb or instrument, with rows of long steel teeth, which open the fibres, and arrange them longitudinally: in the thread spun from combed wool, the fibres or filaments of the wool are arranged in the same manner, or similar to those of flax, and the pieces when woven are not subjected to the process of felting.

The shorter combing-wools are principally used for hose, and are spun softer than the longer combing-wools, the former being made into what is called *hard worsted yarn*, and the latter into *soft worsted yarn*.

Short Clothing-Wool.—The principal qualities deserving attention in clothing-wools are the regular fineness of the hair or pile, its softness and tendency to felt, the length and soundness of the staple, and the colour. The wool-buyer also regards as important the clean state of the fleece, and to the grower its weight is particularly deserving attention; for in fleeces equally fine, from sheep of the same size, some may be much heavier than others, the fibres of wool being grown closer to each other on the skin.

The fineness of the hair or fibre can only be estimated to any useful purpose, in the woollen manufacture, by the wool-sorter or wool dealer, accustomed by long habit to

dilcern a minute difference, which is quite imperceptible to common observers, and scarcely appreciable by the most powerful microscopes. Of the various attempts that have been made to reduce the fineness of wool to a certain standard, by admeasurement with a micrometer, we shall afterwards speak. From some experiments we have made, as well as from those made by Mr. Luccock, Dr. Parry, and others, we may estimate the thickness of the hair of the finest Spanish and Saxony wool to be not more than the fifteen-hundredth part of an inch, and that of the finest native English to be from twelve to thirteen-hundredth parts, whilst the inferior sorts gradually increase to the six-hundredth part of an inch and more. A difference in the size of these fibres, too minute to be noticed by the common observer, may occasion a difference of 40 *per cent.* or more in the value of the wool. The fineness of the hair has been ever considered as an important quality since the clothing manufacture emerged from its rudest state. Fine wool was formerly valued because a finer thread could be spun from it, and a thinner fabric made, than from the coarser wools; but since recent mechanical improvements have been introduced into the woollen manufacture, it has been found practicable to spin coarse wools to the same length as the finer wools were formerly spun to. It is well known, however, to cloth-manufacturers, that whatever be the fineness of the yarn, unless the wool be fine, it is impossible to make a fine, compact, and even cloth, in which the thread shall be covered with a thick soft pile; nor would a thin cloth made from coarse wool have the same durability or appearance as one from fine wool of equal weight *per yard*. Fine wool will, therefore, always preserve a superior value to the coarse; indeed it was long considered as the principal and almost the only quality deserving the attention of the wool-grower, the wool-stapler, and the clothier.

The regular fineness of the fibre is also an object of considerable importance; the lower end of the staple, or that part of the fleece nearest the skin, will sometimes be very fine, and the upper part coarse. In some fine fleeces there will frequently be an intermixture of long, silvery, coarse hairs, and in other fine fleeces an intermixture of short, thick, opaque hairs, called kemps. When the wool is thus irregularly fine or intermixed, it is technically called not being *true grown*. The fine fleeces of Spain and Portugal, particularly of the latter country, are many of them injured by the intermixture of the long silvery hairs before-mentioned: whether this be owing to the original Tarentine breed having been crossed with the coarse-woolled native sheep of Spain, (see the article *SHEEP*), and still preserving a tendency to revert to their first condition, or whether it be the effect of heat on the skin, is uncertain. The Saxony fleeces, from the same breed, removed to colder climates, are generally free from this defect. The coarse short hairs, or kemps, are not uncommon in some of the fine-woolled flocks of England and Wales, particularly those which are more exposed to the inclemencies of the weather, and have a scanty or irregular supply of food. It has been observed, in the first part of the article *SHEEP*, that in some flocks the proportion of fine wool in each fleece is much greater than in others, for in few or none is the wool grown uniformly fine over the whole body.

On the Merino sheep the fleece is more regular, whatever be the degree of fineness, than on any of our native English fine-woolled breeds. The Merino fleece admits of a division into four sorts, the *refina*, the *fina*, and the *tercera*, with a very minute portion of coarse from the flanks and head, which is not sent to market. The three sorts are distinguished in commerce by the marks R, F, and T.

On the average, there will be in each fleece nearly three-fourths of the best or R wool. The second and third sorts, or the F and T, will also contain a considerable portion as fine as the best; but being shorter and discoloured, or intermixed with coarse hairs, which require their locks to be separated from the best sort, or the *refina*.

In the native English fleeces, however fine some part may be, the proportion of the best sort rarely exceeds one-third part, and is frequently not more than one-sixth part of the whole fleece.

The value of the best part of a Spanish fleece, or the R wool, varies greatly in different flocks. When this sort, from the most esteemed flocks, may be worth six shillings and sixpence *per pound* in the English market, the R wool from another flock may not be worth more than three shillings and sixpence. The F and T wools are from 25 to 50 *per cent.* lower than the first sort: thus, the inferior sorts from the finest piles may be of greater value than the best sort or R wool of other piles; but they are never intermixed by the dealers, as they are applicable to different fabrics. In the English mode of wool-sorting, there will frequently be eight or ten sorts in a single fleece; and if the best wool of one fleece be not equal to the finest sort, it is thrown to a second, third, or fourth, or a still lower sort, which is of an equal degree of fineness with it. The best English short native fleeces, such as the fine Norfolk and South Down, are generally divided by the wool-sorter into the following sorts, varying in degree of fineness from each other, which are called,

Prime,
Choice,
Super,
Head,
Downrights,
Seconds,
Fine abb,
Coarse abb,
Livery,
Short coarse or breech wool.

Besides these sorts of white clothing wool, two and generally three sorts of grey wool are made, consisting of locks which may be black, or intermixed with grey hairs. Some wool-sorters also throw out any remarkably fine locks in the prime, and make a small quantity of a superior sort, which they call picklock. The origin of some of the above names is obscure, but the names of the finer sorts appear to indicate either a progressive improvement in the quality of the wool, or in the art of wool-sorting. The relative value of each sort varies considerably, according to the greater demand for coarse, fine, or middle cloths; and the variation during and since the late war in the Spanish peninsula has been much increased by temporary causes. Before that period, when the R wool of good Spanish piles sold at from five shillings and sixpence to six shillings *per pound*, the prime from Herefordshire fleeces was sold at about three shillings and sixpence, and that from the Norfolk and South Down from three shillings to three shillings and two-pence *per pound*. The higher price of the Herefordshire was in part owing to its being in a cleaner state. The Spanish wool is also cleaner than any of the English wools, being scoured after it is shorn; but the latter is only imperfectly washed on the sheep, previously to its being shorn. A pack of English clothing wool of 240 pounds weight, in its marketable state, will waste about 70 pounds in the process of the manufacture: the same quantity of Spanish wool, as sent to market, will not waste more than 48 pounds

on the average. This contributes to enhance the difference between the prices of each, as well as the superior fineness of the latter.

Different wool-sorters make a considerable variation in their modes of sorting the same kind of fleeces: some divide them into more sorts than others; but the following table will shew what may be taken as the average relative value of each sort, when the prime is worth about three shillings and two-pence *per* pound, and may serve to shew the skill required to estimate the value of fine English wool in the fleece.

		s.	d.		s.	d.
Prime	-	3	0	to	3	4
Choice	-	2	4	to	2	8
Super	-	2	0	to	2	2
Head	-	1	8	to	1	10
Downrights	-	1	5	to	1	6
Seconds	-	1	3	to	1	4
Fine abb	-	1	0	to	1	1
Coarse ditto	-	0	9	to	0	10
Livery	-	0	8	to	0	10
Short coarse	-	0	7	to	0	8

The demand for coarse woollen goods having greatly increased of late, the prices of the lower sorts are considerably advanced from the above-stated prices, and are at present as under:

	s.	d.	
Short coarse	1	4	
Livery	1	5	
Fine abb	1	6	
Seconds	1	7	
Downrights	1	8	
Head	1	10	<i>per</i> pound in London.
Super	2	0	
Choice	2	2	
Prime	2	6	
Picklock	3	0	

The Softness of fine clothing Wool is next in importance to the fineness of the fibre, though it has been too little attended to in the culture of English wool. This quality is not dependent on the fineness of the fibre; it consists in the peculiar feel which approaches to that of silk or down, but in which the wool of all European sheep is inferior to that of Eastern Asia, or to the wool of the vicuña, or lama of Peru and Chili. In foreign European wools there are different degrees of this property, where the fibre is equally fine. In our native English wools, the like difference exists between the softness of wool possessing the same degree of fineness, but grown in different districts. In the harder wool, the fibre is elastic and hard to the touch, and cloth made from it has the same harsh feel; it is also more loose in its texture, and the surface of the thread is generally more bare. The difference in the value of cloth from two kinds of wool, equally fine, but one distinguished for its softness, and the other for the contrary quality, is such, that with the same process and expence of manufacture, the one will make a cloth more valuable than the other from twenty to twenty-five *per cent*.

Though the English woollen manufactures had been carried on for so long a period, the cause of this difference in cloths made from wool equally fine was but very imperfectly known till the present century. Mr. Robert Bakewell, then of Wakefield in Yorkshire, first directed the attention of wool-growers and manufacturers to this subject, in a work, entitled "Observations on the Influence of Soil and Climate

on Wool." The reason why the manufacturers remained so long ignorant respecting it arose, he observed, from the manner in which the woollen-trade had been carried on in Yorkshire, the great seat of the manufacture of English clothing-wool, the division of employment there not permitting the wool-dealer, or even the clothier, to witness the final result of the process. The wool-buyer in the distant counties, and the wool-sorter, who divided the fleece, were equally unacquainted with the cloth manufacture. The Yorkshire clothier sold his goods in an undressed, and often in an undyed state; they were bought and finished by the cloth merchant, who was formerly unacquainted with the previous processes of the manufacture, or the qualities of wool. In a promiscuous lot of undressed cloth bought at the same price, and apparently of the same quality in the rough state, if some pieces were finished much better and softer than others, it was attributed to lucky chance, the patron divinity of the ignorant. Mr. Bakewell proved that the hardness of English wools does not depend on the nature of the food, or even entirely on the breed; it is the effect of the soil acting on the surface of the fleece. The wools from chalk districts, or light dry calcareous soils, have the natural yolk or moisture absorbed by the particles of calcareous earth that penetrate the fleece, and the wool is thereby rendered hard. The same effect is produced on a skin where lime is used; it may also be produced by keeping wool for a longer or shorter time in a dry hot temperature; and when wool has been so dried, no process will restore to it its pristine softness. On the contrary, wools grown on rich loamy argillaceous soils are always distinguished for their softness. The quantity of grease or yolk in the fleece has a considerable degree of influence on the softness of Merino wool, the pile being so close as in a considerable degree to prevent the earthy particles from penetrating the fleece; but in all English fleeces the wool is grown thinner on the skin, and admits the more easy access of the absorbent particles. Exposure to the direct rays of a summer sun has also a tendency to injure the soft quality of the wool. We shall have occasion to refer to the methods recommended by Mr. Bakewell to improve the softness of wool on soils naturally unfavourable to its growth.

Of fine European wools, the Saxony generally possesses a greater degree of softness than the Spanish, which we believe to be owing to the sheep being less exposed to the action of light and heat. The native fine Italian wool, before the introduction of the Merino race, possessed a considerable degree of softness, judging from wools which we have seen from thence, but they were deficient in soundness, and not *true grown*. The wools on the chalk soils in the southern and eastern side of England are generally hard, except, as in Kent, where the chalk is covered by thick argillaceous beds. Nottingham forest, Chamwood forest in Leicestershire, and some parts of Shropshire, produced not the finest, but some of the softest wools in England before the late inclosures. The Cheviot hills in Cumberland are not pastured by the finest-woolled English sheep, but their fleeces possess a degree of softness exceeding any from the other districts of England, and they are rendered soft by artificial means, which we shall describe. It is still somewhat uncertain, whether there are two distinct breeds of sheep, from which the fine shawl wool of India are grown; or whether one species of the animal which yields it is not to be classed with the goat. The fleeces from India, which we have seen, are grown on a very small sheep; close to the skin, there is a wool as soft as the softest fur; this is covered by long coarse hairs growing through it. When the wool is once shorn, the separation of these hairs from the soft

wool is a work of extreme difficulty ; but on the back of the sheep we believe the separation can be made with great ease. The softness of the Indian wool is not even distantly approached in the very softest Merino fleeces from Saxony and Spain ; this may be proved by comparing the finest cassimere cloth from Saxony wool, with the shawls or shawl-cloth of India. The ancient Tarentine sheep, called by way of excellence '*molles oves*,' were treated with peculiar care by the Romans, and clothed in skins, which we believe was intended to preserve the softness of the wool, as it is still practised in some parts of Asia for that purpose. In Europe no experiments have been made directly to improve the softness of wool, though wool approaching in softness to that of India would be a most valuable acquisition to our manufactures. To be convinced of this, it need only be stated, that the yarn from Indian wool has been sold here at three guineas *per* pound, not on account of the superior fineness of the spinning, but for the softness of the wool. For coarse goods, indeed, such as blankets, carpets, and cloths called duffields, raised with a hairy pile, a considerable degree of hardness or elasticity of the fibre is an advantage ; but in all the finer articles of the woollen or worsted manufacture, the opposite quality is of great value.

The felting property of wool is intimately connected with its softness, the softest wools having the greatest tendency to felt, and the hard wools are all defective in this respect. The felting property appears to depend on a peculiar structure of the surface of the fibres, by which they are disposed to move in one direction more easily than another. This is perceptible in drawing a hair through the fingers, first from the end to the point, and again from the point to the end ; in one direction the hair feels perfectly smooth, in the other direction a peculiar roughness is felt. The cause of this is supposed to be owing to the surface of the fibres having laminæ, like the scales of fishes, with the edges laid over each other. Indeed in the furs of some animals we have observed with a powerful microscope, that the surface is composed of laminæ laid over each other, resembling the arrangement of the leaves of the artichoke. On this property the process of hat-making depends ; the short fibres of the fur being repeatedly compressed, move and interlock with each other, so as to form a compact substance ; this motion is further aided by heat and moisture. A similar process takes place to a certain degree in cloth subjected to the strokes of a fulling-mill ; the fibres cohere, and the piece contracts in length and breadth, and its texture is rendered more compact and uniform. This process is essential to the beauty and strength of woollen cloth ; and it is observed, that the softer wools felt in much less time than the harder, and form a closer pile on the surface of the cloth, on which account it is a common practice to mix a certain quantity of soft wool with the hard, to enable the former to felt with more facility.

The length and soundness of the staple of clothing wool is the quality next to be considered. By the staple of wool is meant the separate locks into which the fleece naturally divides in the skin, each lock consisting of a certain number of fibres, which collectively are called the staple.

The best length of staple for fine clothing-wool, if sound, is from two to three inches. If it be longer it requires breaking down to prepare it for the process of carding. Saxony wool, being generally more tender than the Spanish, and more easily broken down, is sometimes four or five inches long ; but as it works down easily, it is preferred, on account of the length of its staple, for such goods which

require fine spinning, as cassimeres, pelisse cloth, and shawls. Much of the English clothing-wool of a middle quality is grown longer than is desirable for the purpose of the clothier, and when sound is thrown out for the hosiery trade, if the demand for the latter be great. As the grower could not shorten the length of the staple without diminishing the weight of the fleece, he has no motive to induce him to grow shorter wool ; but the object might be obtained with much benefit to himself by shearing twice in the year, once the latter end of April, and again the latter end of August ; the wool would then be grown of a suitable length for the card, and from experiments that have been made we believe the weight would exceed what can be obtained from one clip : the increase would not be less than fifteen *per cent.*, and the condition of the sheep thereby improved.

The soundness of the staple in clothing-wools is not so important as in combing-wools ; but for some kinds of colours which injure the wool, it is particularly desirable that the fibre should be sound and strong ; this is judged of by drawing out the staple and pulling it by both ends. The soundness and strength of the staple depend primarily on the healthy state of the animal, and on a sufficient supply of food. The staple on some parts of the fleece will always be more tender than on other parts, but by mixture they tend to form a dense pile on the surface of the cloth.

The colour of the fleece should always approach as much as possible to the purest white, because such wool is not only necessary for cloths dressed white, but for all cloths to be dyed bright colours, for which a clear white ground is required, to give a due degree of richness and lustre. It is probable that all sheep's-wool was first of a black or reddish colour : the latter is often referred to by the ancients. Before the invention of dyeing, coloured wool must have had a preference to white ; but after the act of communicating beautiful colours to the fleece, white wool would be in the greatest demand, and those sheep which had white fleeces would be selected to breed from. The most ancient flocks of sheep which we have any record of are those of Laban and Jacob, described in the book of Genesis. The fleeces appear to have been principally brown, or spotted and striped, which was in all probability the general colour of the flocks throughout that part of Asia. We learn that in the course of twenty years a great change was effected in the colour of a large portion of the sheep of Laban : though Jacob appears to have concealed from his father-in-law the method by which this change was effected, we are expressly told in the sequel that it was by crossing with rams which had fleeces of the colours required.

Dark-brown or black woolled sheep are not uncommon in many parts of the European flocks, but such wool being of less value than the white, these sheep ought always to be expelled. Some of the English fine-woolled sheep, as the Norfolk and South-Down, have black or grey faces and legs. In all such sheep there is a tendency to grow grey wool on some part of the body, or to produce some grey fibres intermixed with the fleece, which renders the wool unfit for many kinds of white goods ; for though the black hairs may be too few or minute to be detected by the wool-sorter, yet when the cloth is soiled they will become visible, forming reddish spots, by which its appearance is much injured. The Herefordshire sheep, which have white faces, are entirely free from this defect, and yield a fleece without any admixture of grey hairs. We have no doubt that by carefully rejecting those sheep from the South-Down flocks, in which the grey is most apparent, this defect might be gradually removed. It is particularly desirable with respect

in these sheep, as the wool grown on chalk soils, though less soft than on other soils, is generally whiter, and better suited to such goods which require the process of bleaching or stoving, and do not require to be so much fulling as many other cloths.

The ancients were so well aware of the necessity of expelling dark-coloured wool from their flocks, that in selecting the sheep to breed from, they did not trust to the colour of the fleece alone, but carefully examined the mouth and tongue of the ram, and if the least blackness or swarthiness appeared he was immediately rejected; and though some moderns have doubted the use of this precaution, we believe it was well founded.

“*Illum autem, quamvis aries sit candidus ipse,
Nigra fubeft udo tantum cui lingua palato,
Rejice, ne maculis infuscet vellera pullis
Nascentem.*” Vir. Georg. iii.

Pliny also states, that particular attention was on this account had to the colour of the mouth. “*Arietum maxime spectantur ora.*” We are informed that this kind of inspection takes place in the Spanish flocks at present, a practice in all probability derived from the Roman shepherds, as we believe the flock to have been from those of Italy, or the Tarentine breed. The colour of the soil on which sheep graze, if very dark or red, communicates to the wool a tint more or less strong, which is indelible, and renders such wool less proper for cloths or hosiery goods that are to be finished white; for though the colour may be improved by stoving, yet on washing the cloths, they soon return to a brownish or yellowish tint. The tint from the soil is, however, rarely of sufficient strength to be regarded for dyed goods, excepting for exceedingly light colours.

The cleanness of wool is principally regarded by the purchaser, as it affects the weight. To the grower those fleeces are generally the most profitable that are well filled with the grease, or yolk as it is called, because it keeps the wool in a sound state, and improves its softness. It ought, however, to be washed out as much as possible before it is exposed to sale. The fleeces of the Merino sheep are more plentifully supplied with yolk than those of any of our native fine-woolled breeds; indeed it is so abundant, that the English mode of washing on the back of the sheep will scarcely produce any effect upon the fleece. The yolk or grease in the fleece appears, from the experiments made upon it by M. Vauquelin, to be a native soap, consisting principally of animal oil combined with potash. It is most copiously produced in those breeds which grow the finest and softest wool, and is always most abundant on those parts of the animal which yield the finest parts of the fleece. To this subject we shall again refer in treating of the improvement of wool. This yolk, though so beneficial to the wool in a growing state, becomes injurious to it when shorn; for if the fleeces remain piled in an unwashed state, a fermentation takes place, the yolk becomes hard, and the fibre is rendered hard and brittle. This effect takes place more rapidly in hot weather. The Spaniards remove this yolk in a great measure by washing the wool after it is shorn and sorted. In Saxony fine-woolled sheep of the same race are washed in tubs with warm water, soap-lees, and urine, and afterwards in clean water.

In England the wool is washed on the back of the sheep by immersing the animal in water, and squeezing the fleece with the hand. From these different modes of washing, the wool is left more or less pure. Mr. Bakewell, in his Ob-

servations on the Influence of Soil and Climate on Wool, has given the following table, containing a statement of the quantity of neat wool in every hundred pounds, taken on an average of each sort, and supposing each to be free from lumps of pitch employed in marking the wool, and cleared from what are called the *dog-locks*. The first column represents the average weight after the wool has been scoured perfectly clean with soap and water, and dried; the second the amount of waste.

	Pure Wool.	Waste.
100 lbs. of English wool washed on the sheep's back	75	25
Ditto Saxony fleece-wool	80	20
Ditto Spanish R, or refine	88	12
Ditto Spanish and Portugal unwashed	75	55
Ditto English fleeces unwashed	60	40
Ditto lightly greased wools of Northumberland washed on the sheep's back	65	35

Hence it is obvious, that the state of the fleece with respect to cleanness is an object of great importance to the wool-buyer. The English Merino sheep, from the difficulty of washing the wool on the sheep's back, have generally been shorn in an unwashed state, and the wool offered for sale in this state. The purchasers were frequently unacquainted with the great amount of the loss it would suffer by washing, and were much disappointed at the result. This circumstance, we conceive, more than any other, tended to prejudice the manufacturer against the Anglo-Merino wool. The wool is also injured by remaining in the grease, as we have before stated, and though this has been contradicted, we have no hesitation in asserting the fact from our own experience. Indeed the French manufacturers of fine cloth assert, that the best wools from Spain, though cleared in a great measure from the yolk, yet still retain sufficient to injure the wool if it be suffered to grow old when it is packed, the yolk becoming rancid and hard, and communicating the latter property to the wool. We have frequently observed this effect in the wools from Portugal, that retain a greater portion of the yolk than those from Spain.

After wool has been washed in the usual manner practiced in England, and piled or packed, a certain process takes place in eight or nine weeks, called *sweating*. This is well known to wool-dealers and manufacturers, but has not been before noticed by any writer that we are acquainted with. It is evidently an incipient fermentation of the remaining yolk; and the inner part of the pack or pile becomes sensibly warm. This process produces a certain change in the wool, whereby it becomes in a better condition for manufacturing, being what is called in the north of England less *fuzzy*. This effect results from a diminution of the natural elasticity of the fibre.

When this fermentation takes place in unwashed wool, it proceeds farther, and injures the colour and soundness of the staple or fibre. A similar effect is produced in wool or cloth which has been oiled, and remains some time in an unscoured state. Instances of spontaneous combustion from heaps of refuse wool remaining in a greasy state have been known to occur, and occasion the most serious accidents in woollen factories.

The weight of the fleece is an object of great importance to the grower. It is generally supposed by the English wool-dealers, that an increase of weight implied an increase of coarseness; indeed the words coarse and heavy are considered by them as synonymous, but this is not absolutely

the case; a fleece grown upon the same animal may be increased in weight either by the fibres becoming coarser, or by their being grown longer, or by a greater number of fibres being grown in the same skin. To the wool-grower it can never answer to increase the weight of the fleece on small fine-woolled sheep, by growing the wool coarser; if this be his object, the long-woolled breeds of sheep are to be preferred. He may produce wool somewhat longer by increasing the quantity of food; but it generally loses something of its fineness, and is less suitable for the cloth trade. He may, however, increase the weight considerably by selecting such breeds as grow the wool close upon the skin, and are thickly covered with wool over every part of the body. In this respect, the Merino sheep have greatly the advantage over any of the native breeds of English sheep; many of them yielding from three to four pounds of pure wool, whilst the finest English fleeces rarely exceed two pounds, and would lose one-fourth of this weight when brought to a pure state by scouring. It has been doubted whether all sheep's-wool, when clean, possesses the same specific gravity; but admitting there may be some variation in the wool from different piles, we conceive that it is too minute to deserve the attention of the wool-grower or manufacturer.

The filaments of fine wool being so minute, it requires an eye habituated by long experience to appreciate the relative fineness of two piles, which may differ in value as much as twenty-five *per cent.* Even those who have been long practised in such examinations find it difficult to form immediately a correct opinion of the fineness, if they are removed for a few weeks from all opportunity of viewing wool. It is not surprising then that the wool-grower, who only directs his attention to the subject during one part of the year, should often be unable to judge whether his wool has improved or not since the preceding summer. On this account it would be highly desirable that some easy and correct method of admeasurement by the micrometer could be invented, which might enable the observer to decide this with certainty. Mr. Daubenton employed a graduated scale, adapting it to the eye-piece of a compound microscope; but his method does not admit of accuracy. Mr. Luccock made use of a more simple instrument, which we have seen; it consisted of a lens about half an inch in focal length, adjusted to a graduated scale. On this scale a number of fibres were stretched and compressed by a slider and screw into a given space; the filaments covering this space were then counted by the aid of the lens, and a number of admeasurements being taken of the same sort, the mean of the whole was supposed to give the correct diameter of the filament. In this method, however, some of the filaments must unavoidably overlap part of the others, on which account a greater number will be seen in a given space than there would be were the whole diameter of each fibre visible. The error resulting from this may be stated at one-fifth. Thus Mr. Luccock makes the best English wool to measure the fourteen-hundredth part of an inch, which is finer than the best Spanish, as measured by Dr. Parry, by a more accurate but more laborious method. According to Mr. Luccock, a sample of moderately fine Spanish wool reached to the sixteen-hundredth part of an inch; according to Dr. Parry, the very best Spanish is not smaller than the fourteen-hundredth part of an inch.

With the above deduction of one-fifth, which we believe to be a near approximation to correctness, the diameter of the fibres of the best English wool, as sorted in the usual method, will be nearly as follows:

	Parts of an Inc			
Prime	-	-	-	$\frac{1}{1750}$
Choice	-	-	-	$\frac{1}{1650}$
Super	-	-	-	$\frac{1}{1550}$
Head	-	-	-	$\frac{1}{1450}$
Downrights	-	-	-	$\frac{1}{1350}$
Seconds	-	-	-	$\frac{1}{1250}$
Abb	-	-	-	$\frac{1}{1150}$
Fine livery (variable)	-	-	-	$\frac{1}{1050}$

The method of measurement adopted by Mr. Luccock might be sufficiently correct with the deduction of one-fifth, were the instrument always used by the same person, and a similar degree of pressure given in each experiment; but as this is required, it becomes uncertain in its results, and inadequate to practical purposes.

Dr. Parry's method of measurement is effected with an instrument similar in principle to the lamp micrometer of Dr. Herschel, of which an account is published in the Philosophical Transactions for 1782. (See MICROMETER.) An object of a known diameter being placed in the focus of a compound microscope, and strongly illuminated, a piece of white paper is placed horizontally at some distance beneath it; then looking through the microscope with one eye, and keeping the other steadily open, you will see the object apparently projected on the paper, which is to be measured, whilst viewing it, with a pair of compasses. Divide the length of the image so measured with the known diameter of the object, which will give the magnifying power of the microscope. This being found, place the object you wish to measure in the focus, and projecting its image on the paper as before, measure it with the compasses, and divide the result by the magnifying power, which will be the real magnitude of the object required.

The light of a lamp is to be preferred to day-light, and the fibres to be measured are to be stretched on a glass, and waxed down at both ends. The under side of the glass should be blackened with Indian ink, except in three parts, the middle, and near the two ends. The unblackened spaces being placed in the focus of the microscope, ten or more filaments may be examined and measured successively, both in the middle part of the glass, and near the ends, which will give the diameter of the filament at the upper and lower end of the staple, and in the middle. Each lock of ten filaments being thus examined in three different parts, the mean of the three measurements must be taken for the mean diameter of each filament, and the mean diameter of the ten filaments may be taken for the fineness of the whole lock.

In place of the blackened glass, we would recommend a thin slide of ivory or brass, about five inches in length, and half an inch in breadth, with three transverse slits or openings, one in the middle, and the two others about three-fourths of an inch from each end. On this slide the filaments may be stretched, it will not be liable to break, and the edges of the filaments will be more correctly defined than when a plate of glass is placed under them.

The farther the paper is removed from the eye, the larger will be the apparent space covered by the image of the object, but it must not be too far for the hand to measure it with compasses. But if in place of the compasses we have a sheet of pasteboard graduated into minute divisions from a black line upwards, and a sliding index be adjusted, the pasteboard may be placed at a much greater distance, the observer adjusting the slide, until the edge of it and the black line coincide with both edges of the filament. An

horizontal position for the microscope will be the most convenient, illuminating the object with a lamp and lens. In this way, the apparent diameter may be greatly increased, and we think the observations might be made with greater ease and accuracy.

By the above method the diameter of very minute filaments may be ascertained, and minute differences detected, which the unassisted eye is unable to detect. We are aware, however, that it requires some address and time to enable the observer to manage the instrument, on which account it cannot, we fear, be made generally useful.

The following admeasurements of different fine wools were taken with Dr. Parry's instrument; the first column represents the outward end of the filament, the second the middle, and the third the bottom, in fractional parts of an inch; the latter column the mean of ten filaments of the same wool.

TABLE of comparative Diameters of the Filaments of various Clothing Wools, by Dr. Parry.

	Outward End.	Middle.	Inner End.	Mean.
Spanish Ewe - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Lasteria Pile - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Ewe - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Coronet Pile - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Native Merino Ram -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Saxon - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Picet's Merino Ram -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Best Negrette Pile -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Alva Pile - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Rambouillet Ewe -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Imperial Pile - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Morre - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Ryeland - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
South Down - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Anglo Negrette Ram -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Negrette Ram, Marquis } of Bath - - - }	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Charenton Ram - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Ryeland Ram - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Cape, 4th Cross - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Wilt's Ewe - - -	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$

Long Wool, or Combing Wool, being prepared for spinning by a process entirely different from that of short or clothing wool, and the pieces made from it being finished in a very different manner, the qualities most required in this kind of wool are length and soundness of the staple, without which the fleece is unsuited for the comb. The fineness of the hair is a secondary quality, required only in certain kinds of goods. The wool-comb is an instrument of simple construction, consisting of a wooden handle, with a transverse piece or head, in which are inserted three rows of long steel teeth. The wool, which is to be combed after being clean scoured, dried, and oiled, is first drawn upon these teeth with the hand, until the comb is sufficiently loaded. It is then placed on the knee of the comber, and another comb of a similar kind is drawn through it, and the operation is repeated till all the hairs or fibres are combed smooth in one direction. This operation requires considerable strength, but the comb being previously heated, and the wool thoroughly oiled, facilitates the process. When completed the

combed wool is drawn off with the fingers, forming what is called a *sliver*; the shorter part of the wool sticks in the teeth of the comb, and is called the *noyl*: this is sold to the clothiers.

From the above description, it is evident that if the staple of the wool be not found, the greater part of it will be broken by the process of combing, and form noyls. The staple must also have a sufficient degree of length for the combs to operate upon it. Length and soundness of the staple are therefore the most essential and characteristic qualities of combing-wools.

Long wools may be classed into two kinds: first, those suited for the manufacture of hard yarn for worsted pieces; and second, those suited for the manufacture of soft yarn used for hosiery. The former require a greater length of staple than the latter. The first may therefore be called long combing-wool, and the latter short combing-wool; between these there are gradations of wool, which may be applied to either purpose.

Long combing-wool should have the staple from six inches to eight, ten, or even twelve, in length. Before the recent improvements in spinning by machinery, a very great length of staple was considered as an excellence in long combing-wools; and on this account the hog-wool, or the first fleeces from sheep which had not been shorn when lambs, was more valuable than the wether wool from the same stock, and bore a higher price than the former, by at least fifteen *per cent*. Since that time the wether wool has risen in relative value on account of the evenness of the staple, each lock being nearly equally thick at both ends; but the staple of hog-wool is pointed, or what is technically called *spirey*. Eight inches, if the wool be found, may be regarded as a very proper length for heavy combing-wools. The longer stapled wool was formerly worked by itself, and used for the finer spun yarn, or mixed in small quantities with the wether wool, to improve the spinning. It is found that an equal length of staple contributes to the evenness of the thread when spun by machinery, and a very great length of staple is rather injurious than otherwise in the process of machine spinning. To the wool-grower, however, it must always be desirable to increase the length of his heavy combing fleeces, as he thereby materially increases the weight; and we have not yet learned that the price has ever been reduced on this account, for if the wool be too long for some branches of the worsted manufacture, there are others in which it may be worked with advantage.

The length of the staple may be increased by a plentiful supply of nutritious food. The same effect may also be produced by letting the wool remain a longer time on the sheep before it is shorn. We have seen a staple of Lincolnshire wool which was twenty inches in length: it had grown two years without shearing. This, however, would be unattended with any advantage to the grower. The more frequently sheep are shorn, provided the wool is sufficiently long, the greater will be the weight grown in a given time on the same animal; for, from observations which we have made, we are satisfied that wool is grown more rapidly immediately after the sheep are shorn than at any other time. Length of staple in wool depends primarily on the breed, but may be more affected by culture than many other qualities of the fleece. The soundness of the staple may be easily judged of by pulling both ends of it with the fingers with considerable force. In weak or unsound wool the staple easily breaks in one or more parts, and on observing it, it will be seen that the fibres are much thinner in the part which breaks. This is occasioned either by a deficient sup-

ply of food, by disease, or by inclement seasons, which cause a stoppage in the growth of the fleece. This goes on to a greater or less degree. In some instances, the stoppage has been so entire that the upper part of the staple is nearly separated from the lower, and is only connected with it by a few filaments: in such cases, the stoppage has continued for a considerable time, and the bottom part of the staple may be considered as a new fleece, protruding the old one from the skin. Connected with the soundness of wool, there is another property required; this is, that the staple be free and open, or that the fibres shall not be matted or felted together; an effect which takes place frequently when the wool is unsound. It is in fact a natural felting of the wool on the back of the animal, when by any cause it has ceased to grow. Sometimes the lower part of the fleece next the skin will be so completely matted as to form a substance nearly as hard as a hat, and will hold to the skin by a few hairs only. These are called cotted fleeces; all approach to this state is peculiarly injurious to combing-wools. The wool-buyers generally throw out the cotted and unsound fleeces when they pack the wool from the grower, and buy them at a very reduced price. The softness of combing-wool, though of less importance than in clothing-wool, yet enhances its value, as it is found that such wool makes a closer and softer thread, and in every process of the manufacture finishes more *kindly*. Combing-wools grown on light calcareous soils are deficient in this respect; such are the combing-wools of Oxfordshire and the Cotswold hills, which are formed of that species of lime-stone called oolite, or roe-stone. A copious supply of the yolk is necessary to the healthy condition of the fleece, and as this in many flocks is nearly equal in weight to the wool, the fleeces contain from six to eight pounds or more of it before they are washed, for in the unwashed state they often weigh eighteen pounds in many of the long-woolled flocks in England.

The whiteness of the fleece is less important in the long combing than in clothing wool, provided it be free from grey hairs. The latter circumstance does not frequently occur in combing-wools. There is, however, a peculiar colour communicated by the soil, which is sometimes so deep as to injure the wool for particular uses, and what is of more importance, there is a dingy-brown colour given to the fleece by impoverished keeping or disease, which is called a *winter stain*; it is a sure indication that the wool is not in a thoroughly sound state, and such fleeces are carefully thrown out by the wool-sorter, being only suited for those goods which are to be dyed dark colours.

The fineness of heavy combing-wool is of less importance than the other qualities. In every fleece of this kind there will be a certain small portion of short clothing-wool on the shanks, the belly, the throat, and the buttocks. The clothing-wool from such fleeces is not often divided into more than two or three low sorts, and the combing-wool is seldom thrown into more than four sorts, that is, two sorts of the hog-wool, and two sorts of the wether-wool, of which three-fourths, if the fleece be good, will form the best sort in each.

There is, however, a fine long combing-wool which is required for bombazines and the finer kinds of worsted goods; this is most frequently selected from the longer parts of clothing fleeces, and admits a division into four or five sorts, the finest being equal in hair to that of the head or super in clothing-wool; whereas the best sort of the common heavy combing-wools seldom ranges higher in point of fineness than the coarsest sort of clothing-wool above the breech locks; viz. the low abb and the livery.

Short combing or hosiery wool requires a different length of staple, according to its fineness: for the better sorts, the staple should not be shorter than four or five inches; the lower sorts may range as high as eight inches. A greater length than this is not desirable for any kind of soft worsted. What has been said of the soundness and fineness of staple required for long combing-wool, applies equally to the hosiery wool, but in this the fineness of the hair and softness are of more importance. Most of the fleeces which yield fine combing-wool produce nearly an equal quantity of short wool, which is thrown in the same manner as the regular clothing sorts. The combing sorts for the hosiery are generally called,

Super matching,
Fine matching,
Fine drawing,
Altered drawing,
Brown drawing,
Saycraft.

The names of these sorts derive their origin from ancient processes of the manufacture, with which we are unacquainted at present. The lower sort, or saycraft, was probably at first the long coarse combing-wool, thrown out for the manufacture of says, of which we have frequent mention in the earliest history of the woollen trade in England. The relative value of these sorts, compared with each other, varies according to the demand for the finer or coarser kinds of hosiery, and is also affected by the clothing trade. When any clothing sort which ranges in fineness with one of the combing sorts is in great demand, the wool-sorter will break down the shorter combing-wool of this sort, and throw it to the clothing-wool, which enhances the price of the former by making it scarce. The fineness of these sorts out of the best combing-wools, stated numerically, as compared with clothing sorts, will be nearly as under, in the fractional parts of an inch.

Super matching	-	-	$\frac{1}{84}$
Fine matching	-	-	$\frac{1}{78}$
Fine drawing	-	-	$\frac{1}{70}$
Altered drawing	-	-	$\frac{1}{60}$
Brown drawing	-	-	$\frac{1}{50}$
Saycraft	-	-	$\frac{1}{45}$

Most of the best sorters throw out the hog combing-wool from the best sorts, making a superfine hog for the bombazine trade, hog-wool being less suitable for the hosiery, which does not require yarn so finely spun as for hard yarn.

As all the different sorts of short combing-wool, together with several sorts of clothing-wool, will frequently occur in one English fleece, it is obviously the interest of the grower that his fleece should produce as great a proportion of the best sorts as can be done without materially diminishing the weight.

Skin Wool, or *Pelt Wool*, is the wool separated from the skins of slaughtered sheep by the fellmonger. The quantity of this wool, in a country like England, where so much animal food is consumed, is very considerable, and has been estimated at near 50,000 packs of 24lbs. *per annum*, for England and Wales. Soon after shearing, the skin-wool is too short to be worked by itself, and is generally kept and mixed in with the longer wools. The process by which wool is separated from the skins has a tendency to make it hard, and destroy or injure its felting or milling property, on which account short-skin wools are seldom used for the manufacture of cloth, but more generally for flannels, ferges, and those kinds of goods which require little or no milling;

the finest kinds are much used for stockings made of yarn from carded wool. In the spring, when the wool on the skins has acquired a considerable length, it is thrown into combing sorts; the finer kinds are used for knitting hosiery yarn, and the coarser for hard yarn for the warps of serges and other goods, having a warp of combed and a weft of carded wool. The value of skin-wool is seldom equal to that of fleece-wool of the same degree of length and fineness, owing to the felting property being injured, which renders it more unfit for the manufacture of woollen cloth.

Lamb's Wool.—The wool of the lamb is, with certain exceptions, softer than that of sheep's-wool, from the same flocks. It possesses the property of felting in a remarkable degree, and on this account is principally manufactured into hats, except skin lamb's-wool, which losing its felting property in a great degree, is employed in the manufacture of flannels and woollen yarn for lamb's-wool hosiery. In the northern parts of Europe, the lambs of some of the breeds of sheep possess a fleece so delicately soft, that it constitutes a most valuable fur, being dressed on the skin, and used as a costly article of attire. According to Pallas, the inhabitants of the Ukraïn and Podoli, as soon as the lamb is dropped, (which comes into the world with a pretty wavy skin, even without the assistance of art,) to augment its beauty, and make it bring a higher price, sew it up in a sort of coarse linen shirt, so as to keep up a constant gentle pressure on the wool, pouring warm water over it every day to make it soft and sleek; only letting out the bandage a little from time to time as the animal increases in size, but still keeping it tight enough to effect their purpose, which is to lay the wool in beautiful glossy ringlets, and thereby produce a delicate species of fur in great request for lining clothes and morning-gowns. By this treatment, the staple of the fine soft wool which rises in the infancy of the lamb takes a handsome arrangement; and the animal is killed younger or older according to the species of fur intended to be produced; from a short glossy nap, like satin, only fit from its thinness for the purpose mentioned above, to a warm thick fur for a winter great-coat. The first of these furs in estimation and price is a fine black, that looks like silk damask; an inferior black fur comes next, much thicker, used for *pelisses*, or *shubes*, as the upper winter garb worn out of doors is called; and the least in estimation is the whitest, except it be of a very pure colour and silky appearance, where it is a rival to the first; especially for night-gowns, a very common dress both morning and evening amongst the Russians; particularly in the interior parts of the empire.

The Bucharian sheep, as described by Pallas, grows a compact, soft, and elastic wool, which is elegantly formed into frizzled ringlets. In the lamb, the wool is formed into delicate little circular waves, as if pressed close to the skin by art; but when taken from the mother, or killed immediately after birth, they are still more beautiful, and often elegantly marbled with feathered waves, like silk damask. These three furs are the finest and most precious of the kind known to Europe and the East; they are brought to us by the Bucharian Tartars and Persians, who sell them dear. The most prized are, the *blue*, the black, and the silver grey; but of the *unborn lamb-skins*, as the fine glossy thin furs are called, which so much resemble silk damask, the fine black is dearest and most esteemed. To obtain these valuable furs, the Bucharian Tartars purchase whole flocks of male lambs just dropped from their mothers: as to kill a female till past the age of breeding is held as a kind of crime by all Tartar hordes; such is their reverence for an animal which constitutes their greatest riches, and the propagation and care of

which are the great business of their lives; so that all the fur we see of this species sold by the Tartars are from young rams. The Bucharians are of opinion, that art is necessary to preserve these furs in their greatest beauty; and under that idea, keep the lambs under shades, &c. during the meridian ardour of the sun; but Dr. Pallas has reason to think, that these precautions are useless, as he observed that the same variety of sheep produced the same fine hues equal in every respect, without any sort of care, in the hands of the Kirguite Tartars.

It is very remarkable that the lamb's-wool, in many of the Merino flocks, is coarser than the sheep's-wool. In some of the flocks, the lambs are at first covered with coarse hair, which falls off afterwards, and they produce the finest wool.

Wool from other animals besides the sheep is employed in manufactures, and spun and woven into fabrics of different kinds, either unmixed or mixed with sheep's-wool. The goats of Thibet, which grow the fine shawl wool, produce it as a fine down at the bottom of the long coarse hair, with which the animals are covered. Many of the common goats in Europe grow a similar down, which, by cultivation, might become a valuable article of commerce. It is not, however, yet clearly ascertained, whether the shawls and shawl cloth of India are all manufactured from goat's-wool; part of it appears to be made from sheep's-wool peculiarly soft and fine. The Angora goat grows a hair extremely fine and silky, which is much used in some of the French worsted goods mixed with silk. This goat is properly a long-woolled animal. Dr. Anderson says, that the Angora goat will prosper and preserve its peculiarities in France and Sweden. The wool of the vicunna, called Vigonia wool, is generally of a reddish-fawn colour; it is peculiarly soft and silky, but intermixed with long coarse hairs, which are very difficult to separate. (See VICUNNA.) From the lama and pacos of Peru a stronger and longer stapled wool is obtained, which is sometimes white. Under a liberal government which protected and encouraged commerce, we have no doubt the fleeces of these animals might be greatly improved, and would become an article of great value. The wool from the yak of Tartary, and the musk ox of Hudson's bay, has yet received little attention. We have seen stockings made of the latter, and which are worn in that country; the wool was soft but not fine, and much intermixed with long coarse hairs.

The quantity of sheep's-wool annually grown in England and Wales was estimated, by persons in the wool trade examined before the house of commons in the year 1800, at six hundred thousand packs. Mr. Luccock, in his Treatise on Wool, seems to consider this estimate as greatly exceeding the real amount, and has given an estimate founded on the supposed extent of surface pastured by sheep, and the quantity of sheep *per* acre in each county. This table we subjoin, as the only attempt that we know of to determine the question on certain data; though we consider it only as an approximation to truth, and are inclined to believe that the quantity is under the real amount. Such is also the opinion of the most intelligent persons in the wool trade, whom we have had an opportunity of consulting.

From this table, it will appear that the total amount, including skin-wool and lamb's-wool, is somewhat short of four hundred thousand packs, which is probably one-fourth below the true quantity, could it be ascertained. Mr. Luccock is inclined to believe that the flocks of sheep in England and Wales are not so numerous as formerly, but he says those of Ireland and Scotland are rapidly increasing. Even in England and Wales, he says, we have

more than three millions of acres capable of being improved, and carrying a more numerous stock. We have two millions of sheep whose fleeces are scarcely wool, and which might be brought to contribute their share to support the woollen manufacture, and to increase the wealth of the country.

It may be proper to remark, that the quantity of wool grown annually in England is more variable than is generally supposed, owing to the variable temperature of our climate. In long-continued and severe winters, the sheep not obtaining the same quantity of food, and being also rendered less vigorous by the cold, do not grow so much wool as in milder seasons. The difference between the weight of the fleeces grown in severe and in very mild seasons, may be stated at one-fifth of the whole annual clip: indeed we believe it exceeds that proportion. About the year 1700, the annual value of English wool was estimated at two millions sterling. If we suppose the average price at that time to have been eight-pence *per* pound, or eight pounds *per* pack, this will make the total weight of wool two hundred and fifty thousand packs. Indeed when

we consider the improved state of our agriculture, the great increase of our population, and of our woollen exports, we may fairly state the present weight of wool grown to be double the amount of what it was at the period referred to. In a subsequent part of this article, it will be seen that the cloth manufactures of Yorkshire, principally from English wools, have increased eight-fold in the last eighty years; and though the woollen manufactures have removed from some other situations, yet the great increase on the whole in England cannot be doubted. Since the date of Mr. Luccock's table in 1805, in consequence of the high price of long combing-wool, the growers have paid more attention to the weight of their fleeces; and many who had rendered their fleeces lighter by exchanging the Lincolnshire for the Leicester breeds of sheep, have since been reverting to the former breed, or rather to a mixed breed, endeavouring to combine the improved form of the Leicester sheep with the heavy fleece of the Lincoln. The quantity of long combing-wool grown annually is greater than it was even ten years since; the high and increasing price and demand operating naturally as a premium for its cultivation.

TABLE I.—Shewing the Produce of English Long Wool.

District.	County.	No. of Acres.	No. of Sheep.	Weight of Fleece.	No. of Packs.
Teefwater -	{ Durham - - - - -	100800	67200	9	2520
	{ Yorkshire - - - - -	61250	14310	8	477
	{ Holderness - - - - -	127680	84000	8	2800
	{ Lincoln rich land - - - - -	413875	1241625	9	46561
Lincoln -	{ marshes - - - - -	175000	87500	8	2916
	{ miscellaneous land - - - - -	758485	505657	8	16855
	{ Norfolk - - - - -	55428	38500	7	1223
	{ Cambridge - - - - -	187600	41688	8	1390
Leicester -	{ Huntingdon - - - - -	87500	87500	7	2552
	{ Leicester - - - - -	398650	380528	7	11100
	{ Northampton - - - - -	560000	640000	6	16000
	{ Rutland - - - - -	117000	114000	5	2370
Kent -	{ Warwick - - - - -	182875	160000	5	3333
	{ Stafford - - - - -	14000	3720	7	113
	{ Romney Marsh - - - - -	46920	185000	7	5400
	{ Other Marshes - - - - -	65000	108330	7	3160
Devonshire -	{ South Hams - - - - -	387500	193750	8	6458
Cotswold -	{ Gloucester - - - - -	200000	200000	8	6666
		3939563	4153308		131794
Slaughtered		1176770	Sheep		
		196128	Producing long-skin wool	5720	Packs.
			Carrian wool	286	
					5434
Neat Total -					137228

TABLE II.—English Short Wool.

District.	County.	No. of Acres.	No. of Sheep.	Weight of Fleece.	No. of Packs.
Norfolk	Norfolk	1260572	683704	2	5697
	Suffolk	817000	497000	2½	5176
	Cambridge	817600	67744	4	1128
	Huntingdon	144000	108000	4½	2000
	Bedford	268800	204000	5	4250
	Essex	778400	519000	3	6486
	Suffex Downs	211200	316800	2	2640
	Low Land	623840	547000	3	6837
	Kent	728000	524475	3¼	7000
	Hampshire	774900	516600	3	6457
Wiltshire	Isle of Wight	87500	61000	3¼	800
	Surrey	327600	283000	3	3540
	Wiltshire Downs	437000	583500	2¾	6684
	Pasture	235000	117500	3	1460
	Berkshire	408800	306600	3¼	4151
	Oxford	380730	304584	Various.	5303
	Bucks	408800	222968	3	2787
	Herts	369600	277000	4½	5297
	Middlesex	76000	45000	4	750
	Dorset	700000	632240	3¾	9880
Western	Devon	873700	436850	4	7280
	Cornwall	812000	203000	4	3382
	Somerset	851200	500700	4½	9338
	Gloucester	528000	355000	Various.	5400
	Hereford	672000	500000	2	4200
	Monmouth	322625	177619	Various.	1431
	Worcester	369600	330504	3½	4820
	Shropshire	739200	422034	2½	4397
	Stafford	549360	183120	2	1526
	Warwick	305925	182962	3	2287
Hereford	Leicester	50000	20000	3½	291
	Lincoln	309120	123648	5½	2833
	Nottingham	435680	255147	Various.	4112
	Derby	553280	362400	3	4530
	Chester	588000	65000	Various.	926
	Lancaster	952000	310000	3½	4522
	York West Riding	1429250	383122	Various.	6678
	East Riding	454720	306240	5	6380
	North Riding	1200000	365326	Various.	5939
	Westmoreland	431200	378400	3½	3262
Heath	Cumberland	856800	378400	3¾	5915
	Durham	414400	159385	5	3320
	Northumberland	1108800	538162	5½	12333
	North Wales	2035200	683040	2	5692
	South Wales	2284800	571200	1½	3570
	Isle of Man	-	-	-	-
		28412202	14854299	202737	
Packs Skin Wool.					
Slaughtered		4221748 sheep	3.25 2	28580	
Carrion		211087		1429	
Slaughter of long-wool sheep		980642	3	12258	
Carrion of ditto brought forward		-	-	286	
					42553
Total of short wool				-	245290
Ditto long ditto				-	137228
Wool from lambs slaughtered				-	2918
Ditto shorn				-	7800
					10718
Grand total				-	393236

N.B.—The average fleece of England, } nearly		lbs.
Do. ————— short wool	-	4
Do. ————— long wool	-	10
Do. stock per acre in }		
England	-	7½ sh.
Do. do. long wool	-	1½ sh.
Do. do. short wool	-	
Do. produce per acre }		
long fleece wool - - - }		
Do. do. short do.	1	5
Do. do. long skin wool	0	5
Do. do. short do.	0	4
Do. do. skin wool of }		
the kingdom, nearly - - }		

The wool of Scotland may, perhaps, be estimated at 70,000 packs, of which the greater part, particularly that grown in the Highlands, is of the very coarsest kind. Of the quantity of wool grown in Ireland, we can form no correct estimate, but it cannot be great. From the returns at the Custom-house, it appears that the quantity of wool imported from Ireland and the Isle of Man in 1816 amounted to about 2600 packs; whilst the value of woollens imported from England was upwards of 500,000*l.* sterling. The woollen and worsted manufactures in Ireland are no where on an extensive scale; perhaps 60,000 packs are the full amount of the wool annually shorn in Ireland: this was the amount stated about a century since.

The quantity of wool imported into England may be seen from the following return at the Custom-house for the year 1817, amounting to about thirty thousand packs. The qualities we have annexed in the last column.

An Account of the Quantity of Sheep and Lamb's Wool imported into Great Britain, in the Year ending 5th January 1817; distinguishing the Countries from whence imported.

Countries from whence imported.	Year ending 5th Jan. 1817.	Quality.
	lbs.	
Russia - - -	228,673	Coarse.
Denmark - - -	80,646	Principally coarse.
Iceland and Feröe - - -	33,395	Coarse.
Prussia - - -	16,712	Fine clothing-wool.
Germany - - -	2,816,655	Principally ditto.
Holland - - -	143,390	Ditto.
Flanders - - -	77,625	Ditto.
France - - -	221,595	Ditto.
Portugal, &c. - - -	493,277	Ditto.
Spain - - -	2,958,607	Ditto.
Gibraltar - - -	25,692	Coarse.
Italy - - -	108,234	Principally fine.
Turkey - - -	26,821	Fine.
Ireland and Isle of Man (produce) }	600,377	{ Various, none very fine.
— (foreign) - - -	1,171	
New Holland - - -	13,611	Fine Merino.
Cape of Good Hope - - -	9,623	Ditto.
United States of America - - - }	43,465	Various.
Spanish colonies in South America - }	206,454	Ditto.
Brazil - - -	5,512	Ditto.
British West Indies - - -	6,329	Ditto.
Total - - -	8,117,864	

The whole of the imported wool, with scarcely an exception, is worked on the card, none of it being suited for the comb. The coarser kinds are principally employed for carpets, &c.; and the fine from Spain, Germany, Portugal, and France, supply our manufactures of superfine broad cloths, cassimeres, &c. So large a portion being of the finer kinds, the total value cannot be less than one million and a half pounds sterling.

Wool of New Holland.—The annual value and amount of the fine wool imported into England for our own manufactures being so great, we must surely applaud the meritorious exertions of those who attempt to supply the demand with the produce of our own country, or of our dependent colonies, and more particularly if they can raise this supply from parts where no wool was before grown. In this view, it cannot fail to be highly interesting to learn, that the exertions of one enlightened agriculturist have been eminently successful in spreading over an immense region dependent on England the very finest-woolled sheep, where the soil had never before yielded any produce serviceable to civilized man.

John Macarthur, esq. descended from an ancient family in Argyleshire, captain in a regiment then commanded by general Grose, went to New Holland in 1789. Fortunately for the future prosperity of the colony, his active spirit of inquiry and enterprise led him to direct his attention to the natural advantages which the soil and climate presented to the agriculturist, and having by purchase and grants obtained a considerable tract of country, he quitted the service in 1793, and commenced his farming operations. His stock at first consisted only of a few oxen and thirty Bengal ewes, growing a coarse kind of wool or hair. About the year 1795, he obtained from captain Kent, of the Royal Navy, one Merino ram and two ewes, purchased from the Dutch governor of the Cape of Good Hope. With these he began to cross his coarse-haired sheep, and to select the finest-woolled progeny to breed from. Having occasion to return to England in 1802, he brought over specimens of his wool, which were shewn to a body of the clothiers from the west of England, then in London on public business, who were so sensible of the advantages which might result from encouraging the growth of fine wool in the colony, that they presented a petition to the privy council, by whom Mr. Macarthur was examined. His plans being approved, the privy council recommended the secretary of state for the colonies to give him an additional grant of land, in a tract of country, from its fertility, called the cow-pastures, forming part of Camden county. On his return he took with him three Merino rams and two ewes, purchased from his majesty's flocks; and thus encouraged, he proceeded with rapid steps in the increase and improvement of his flocks, the climate being every way suited to secure the healthy condition of the sheep, and preserve the fineness of the wool.

The numbers increase four-fold every five years, so that his flocks already amounted to about four thousand sheep and lambs, including the fine and mixed breeds, when the unfortunate disputes with governor Blight, and the subsequent arrest of the latter, obliged Mr. Macarthur once more to return to England, and in some degree interrupted the progress of improvement. In 1817 his flocks had increased to about seven thousand, and the wool which has been sent to this country at different times, is become an important source of profit, the better sort being equal to the best Merino piles from Spain or Saxony. What we have seen more nearly resembles the latter, and were they both in the same state of cleanness, the most experienced eye could not discern any difference between them in fineness of the hair, length of staple, soundness, colour, or other properties.

The wool has been hitherto washed on the sheep's back in the English method, by which it is not rendered so clean as by the Spanish or German mode; but making allowance for the additional waste, its value is equal to that of the very best Merino wool imported from any part of Europe.

The quantity imported this year is about eighteen thousand pounds weight, and a farther arrival is expected. The laudable example of Mr. Macarthur has been followed by other persons in the colony, and the total amount of wool sent from thence this year is about fifty thousand pounds weight; and such is the spirit of agricultural improvement, that at the annual sales of sheep established by Mr. Macarthur, rams and ewes have been sold at from ten to thirty guineas each. Though the absence of Mr. Macarthur impeded the progress of improvement, yet this will be more than compensated by the valuable information he has obtained with respect to the management and improvement of his flocks, from observations made on the continent; and he has further benefited the colony by taking back with him a selection of olive-trees, vines, and oranges. The dryness and mildness of the climate of New Holland, and the almost total absence of briars and underwood, are extremely favourable to sheep. His stock is divided into flocks of about four hundred, with shepherds and Spanish dogs to each. Under these propitious circumstances, and as the flocks double in number every thirty months, we may anticipate, that in the course of twenty or twenty-five years, the importation of fine wool from this colony will be fully equal to the total amount at present imported into England from all the different countries of Europe. It might repay the exertions of this enlightened agriculturist, and of the British government, could they procure from India the animals, whether sheep or goats, which yield the peculiarly soft wool for shawls. This would be a most valuable article, and is much wanted by our manufacturers.

There can scarcely be a doubt, that under the favourable climate of the British settlements in New Holland, all the Asiatic wool-bearing animals, particularly those of Cashmere and Thibet, might be introduced with every prospect of success. The coarse wool grown in the colony is chiefly manufactured in the country for domestic use. It is estimated that there are at present sixty thousand sheep in the colony, and a little perseverance and attention would suffice to change the coarse-woolled breeds into finer ones; a change which is at present rapidly taking place, and deserves the greatest encouragement, as wool is the only article of produce which the colonists have at present to export in exchange for British manufactured goods.

The *Improvement of Wool* depends primarily on attention to the breed of sheep, but there are various circumstances of soil, climate, and food, which are important to be regarded. The experiments that have been made in various parts of Europe within the last half century, have sufficiently removed the prejudice that long prevailed, respecting the impossibility of growing the finest clothing-wool in almost every part of the globe where sheep will subsist and thrive. It is different with the long combing-wools, to grow which in perfection, luxuriant pastures seem absolutely requisite, and these cannot be obtained under a parching sun, nor could the animal subsist in tropical climates, covered with such a load of wool as is grown on our sheep in Lincolnshire. Under such circumstances, an entire change seems to take place in the animal system; the long-woolled sheep become diseased and feverish, and only recover by casting the fleece, which is replaced by a coat of short hair. The rich pasture in England, and the opposite coasts of Flanders, seem more favourable to the growth of heavy combing

fleeces, than any other country in the known world; and the Leicestershire and Lincolnshire sheep seem every way well suited to these pastures, and the prices of the wool obtained at present are sufficient to secure attention to its cultivation. At one period, indeed, during the American revolution, the price of long combing-wool not being more than about three-pence *per* pound, the growers turned their attention principally to the improvement of the carcass, and neglected the weight of the fleece. At present the price is about eighteen-pence, and the average weight being about eight pounds, the wool forms an important object, and the growers are endeavouring to increase the weight of their fleeces. For the common purposes of the worsted manufactures, this wool is so well suited as to leave nothing further to be desired; and it is this kind which foreign manufacturers are so desirous to obtain from us. In many situations, however, where heavy long-woolled sheep are introduced, and where the soil is not sufficiently rich to grow it in perfection, it would be possible to grow a fleece weighing five or six pounds of very fine combing-wool, by crossing the long-woolled ewes with the Anglo-Merino rams. The increasing demand for finer goods, and the great improvement made in the spinning of combing-wool by machinery, make such a change desirable where the pastures are not sufficiently rich to bear the heavy long-woolled breeds of Leicester and Lincoln.

In many cold and exposed situations it would be desirable to provide better shelter for the flocks; and the practice of *grazing*, hereafter described, might be introduced with great advantage, and would tend to preserve the sheep and improve the quality of the wool.

The experiments made on the fine-woolled sheep on a large scale in different parts of Europe, prove that the peculiarities of food and climate have comparatively small influence on the quality of clothing-wool, and that it may be grown equally fine in situations where the sheep are confined and kept on dry meat a great part of the year, as in Saxony, Sweden, and Denmark. It may also be grown in the richest pastures, provided the pastures be over-stocked, to keep the herbage bare. There cannot, however, be a doubt, that a dry light soil, particularly in the moist climate of England, is most favourable to the health of the sheep, and to the quality of the wool.

The experiments that have been made in England on the Merino sheep have not been so successful as in other countries, principally arising from two causes.

In the first place, the demand for meat in England will always make the wool but a secondary object with the grazier, and no cross of the Merino sheep with the English has yet produced a race that equal in symmetry of form the South Down sheep, or that will produce the same quantity of meat to the butcher in the same space of time, and with the same food. In the second place, the mode of washing the Merino and Anglo-Merino wool in England will, so long as it is practised, prevent the wool from obtaining its proper value in the market. From the great quantity of natural yolk or grease in the Merino fleece, it is impossible to wash the wool on the sheep's back by mere immersion in water. In Spain no attempts are made to wash the wool upon the sheep's back, but all the fleeces of a pile are regularly sorted, and the different sorts scoured and dried before the wool is packed. But where the quantity of wool which any one grower possesses is small, as in England, it would not answer to send for wool-sorters from a distance; and to wash the wool before it is sorted, would so intermingle the fine with the coarse locks, as to render the regular sorting extremely difficult and expensive. In

Saxony and Sweden the wool is washed on the sheep's backs. The following account of the process is thus described by baron Schulz. The sheep are first washed with one part clear ley, and two parts lukewarm water, and then in another tub with less ley in the water; after which the sheep are washed, laying them always on their backs, with their heads up, in a tub with clean water; and lastly, there is poured on the sheep, when standing on the ground, a sufficient quantity of water, which is as much as possible squeezed out of the wool. The sheep are afterwards driven into an unpastured meadow adjoining, and remain there, to prevent their soiling themselves in the sheep-house. They remain there a day and a night, or longer, till the wool be dry, which in fine weather will be in three days. Some persons wash their sheep twice, but the wool becomes harder in consequence of it, and has a greyer appearance.

The great quantity of grease which the finest Spanish wool contains at the first washing mixes with the ley-water, and makes it quite soapy; but this grease is wanting in the second washing, so that the water is not in the least softened. Some mode of washing like the above must be introduced in England, before the manufacturer will encourage the Anglo-Merino wool; for after his purchase, when he thinks he has obtained sufficient allowance in the price to cover the waste, he is generally much disappointed in finding the loss in the manufacture so greatly to exceed his expectation, and he is deterred from making a second trial.

In the northern counties of England, and in Scotland, a practice has long prevailed of greasing the sheep with a mixture of tar and butter, to preserve the animal from the effects of moisture, and the inclemency of the weather in hilly and exposed situations. This practice seems at present peculiar to Britain, but the ancients evidently made use of mixtures of the dregs of olive wax, tar, wine, and other ingredients, to protect the skin of sheep after shearing, and to soften and improve the wool. Such was the practice of the Italian shepherds, as described by Virgil:

"Aut tonsum trilli contingunt corpus amurca,
Et spumas miscent argenti vivaque sulfura,
Idæasque picæ et pingues unguine ceras
Scyllamque helleborosque graves nigrumque bitumen."
Georg. lib. iii.

That this practice was extremely beneficial in warm climates, by protecting the skin of the sheep from insects after shearing, and by keeping the wool in a soft state, cannot be doubted.

The practice of greasing the sheep in Scotland, and the northern counties of England, with a mixture of tar and butter, seems to have been introduced merely to preserve the sheep, and was generally supposed to be injurious to the wool. Indeed the great proportion of tar, too frequently employed, gave some ground for entertaining this opinion; and the breed of sheep, on which this mixture was most generally applied, is naturally the worst which exists in Britain for the production of wool, the fleeces more nearly resembling coarse hair than wool; but Mr. Bakewell, in his *Treatise on Wool*, observes, that "in Northumberland, where the fine-woolled sheep have received the benefit of greasing with a mixture in which the proportion of tar was merely sufficient to give it due tenacity, the wool is greatly improved by the process, but the ignorance or selfishness of the wool-buyers for a long time prevented the acknowledgment of the fact." Many were afraid to purchase the wool on account of its dirty appearance, but its value is now better understood in the Yorkshire markets, and it is purchased by the manufacturers of coloured cloth in preference to the ungreased wool

of the same degree of fineness. The same preference is also given to the cloths in the halls, where they are sold in an undressed state. When these cloths are finished, their superiority is more apparent, possessing a degree of softness far beyond the ungreased wool. These wools appear to improve in every process of the manufacture, and yield a cloth of greater value by twenty or thirty *per cent.* than the ungreased hard wools, though the latter may be equally fine.

But even in Northumberland, where the wool is so greatly improved by the practice, its good effects in this respect are not sufficiently known, and the operation is delayed till the approach of winter. By this delay, the upper part of the staple which is first grown, is deprived of the advantage of being kept in a moist soft state during the summer heat. When the operation has taken place, a perceptible improvement may be observed in the wool which is afterwards grown. The line of distinction is clearly marked by the stain which the unguent leaves in the staple, the bottom part of which, where it is applied, is finer and softer than the upper part which was grown before its application. This difference is so great, that a careful examination of the fine-greased wools of Northumberland might alone be sufficient to demonstrate the advantage of the practice, and the inconvenience of delaying the operation to the end of the year. To derive the most advantage from the ointment both to the wool and the sheep, it should be applied immediately after shearing, and again at the approach of winter. By the first greasing, the wool will be kept soft and moist during the sultry heats of July and August, and the top of the staple would not become harsh and discoloured, which is frequently the case with English wool. One acknowledged advantage of greasing immediately after shearing should not be overlooked; it destroys the sheep-tick, and has a tendency to prevent cutaneous distempers, and to protect the skin from the bite of the fly. The manner of preparing the ointment in Northumberland is as follows:—From sixteen to twenty pounds of butter are placed over a gentle fire, and melted; a gallon of tar is then added, and the mixture stirred with a stick until the tar and butter are well combined, and form a soft tenacious ointment. Some skill is required in its application, the want of which has prevented the practice from prevailing more generally. If the ointment be rubbed on the wool, it collects on the top of the staple, where it detains the loose soil, and becomes hard, and is injurious to the wool. The proper method is to divide the staples or locks with one hand, and apply the ointment with the finger immediately upon the skin; it is thus kept constantly soft by the warmth of the animal, and is equally diffused through the fleece. Attention to this circumstance is of the greatest importance to the success of the practice. The quantity laid on each animal varies in different districts. In the lighter mode of greasing, one gallon of tar and twenty pounds of butter will be sufficient for fifty sheep. In Scotland, where greasing is applied merely to preserve the animal against the inclemency of the climate, a much larger portion of tar is used: this would be very injurious to the wool, were it of any other than the very coarsest kind.

Could a cheap substitute for tar be found, which would possess equal tenacity, the ointment might be applied with great advantage to all our native breeds of English sheep, both for the preservation of the animal and the improvement of the wool. Mr. Bakewell states, that long combing-wools, which have been greased in this manner, produce a softer and superior yarn to any ever made from wool of the native English breeds which have not undergone the pro-

cells. On all chalk and light calcareous soils, the wool is always much harsher than wools of the same degree of fineness grown on argillaceous or siliceous soils; and this arises from the calcareous earth penetrating the fleece, and absorbing the natural grease, and thus rendering the fibres hard and elastic. These soils cover a large portion of the south-eastern counties of England, and of some of the midland counties; and it is well known to cloth manufacturers that the wool from these districts do not work so well, nor make so soft a cloth, as wool on siliceous or argillaceous soils. Nor will this wool felt in the fulling-mill like the softer wools. The practice of greasing would be of undoubted advantage in calcareous districts, applying the ointment more sparingly than in the northern counties. Perhaps twenty-five pounds of butter, and one of tar, or two of bees'-wax, might be sufficient for one hundred South-Down sheep; and if the mixture were applied once after shearing, and again in October, the expence would be abundantly compensated by the improved condition both of the sheep and wool. The softness of wool appears to be essentially connected with the property of felting, and depends partly on the structure of the surface of the fibre, and partly on its possessing but a moderate degree of elasticity. The process of felting is best illustrated in the hat manufacture, where the fibres of wool or fur are brought into contact by pressure and warmth, and form a compact substance without the aid of spinning and weaving. In some parts of Tartary, coarse cloth for tents is manufactured by spreading the wool on the ground, and pressing it in warm water with the feet; this was probably the first mode of making cloth. All good woollen cloth is still woven comparatively loose, and is made firm and close in the fulling-mill. The fibres of wool or fur have a tendency to move more easily in one direction when pressed, than in the opposite direction. This motion has been compared to that of an ear of barley placed under the coat-sleeve, with the points of the beards downwards; by the action of the arm the ear is moved in a retrograde direction, until it has advanced from the wrist to the shoulder. When we draw a hair of wool or fur through the fingers in a direction from the points to the root, we can feel a sensible degree of roughness, which is not felt if the hair be drawn from the root to the point. Hence we may suppose, that the surface is covered with a number of points or rings, which are too minute to be observed by the microscope, except in some kinds of fur, as in that from the South-sea seal, in which, with a powerful microscope, we have seen the surface covered with distinct leaves or points, shaped like those of the artichoke. We have a striking illustration of this tendency of the fibre to move in one direction in that particular process of hat-making, where it is intended to cover the felt or substance of the hat with fur of a superior kind. The felt on which this fur is to be laid being finished, the hair of the beaver is uniformly spread upon the surface, and being covered with a cloth, it is pressed and agitated by the hand for a certain time. The fibres of beaver-hair introduce themselves by their roots into the felt, and proceed to a certain depth, and become firmly fixed in it. If the pressure were continued for a longer time, the hairs would pass entirely through the felt, going out at the under surface, as each hair follows the direction it acquired at the beginning of the process.

As the felting property, therefore, seems to depend on the minute structure of the surface of the fibre, it is easy to conceive how this may be injured by a dry calcareous soil, and how this property is best preserved in those furs

which are grown under a covering of coarse hair, and protected from external injury. The process of greasing is in some respects a substitute for such a covering, and not only defends the surface, but prevents the fibre from becoming dry, harsh, and elastic. The ancient Greeks and Romans were in the practice of covering their soft-woolled sheep, called *mottes ovés*, with skins: this has been supposed to have been intended merely as a protection from briars and underwood; but we have no doubt that wool so covered would be much softer than wool exposed to the action of light, and of the soil. That the rays of the summer sun have a tendency to make wool both coarser and harsher, may be seen in the effect produced on sheep that are exposed to it without shelter immediately after shearing. The top point of the staple which was grown at that time is almost always coarser and harder than the bottom of the staple which has been grown under the cover of the upper part of the fleece, and consequently more protected from light. An analogous effect is produced on the skins of horses kept in coal-mines, which become sleek and soft. These facts may suggest to wool-growers desirous of improving their wool, the advantage of providing shade for their flocks during the sultry heats of summer. The natural instincts of sheep might teach them the impropriety, not to speak of the cruelty, of keeping their sheep in summer inclosed in pens, and unprotected, upon a dry soil, where the animals are almost roasted alive; a practice not less injurious to the health of sheep than to all the best qualities of the wool. Next to a regular supply of food, protection from the effects of heat and wet are objects of the first importance in the management of sheep; and it may be stated as an undoubted truth, that whatever contributes to the comfort of the animal, will enable it to fatten with a smaller quantity of food, will tend to preserve it in a healthy state, and will also increase the quantity and improve the quality of the wool.

WOOL, Chemical Examination of. The chemical properties of wool are very similar to those of hair, and as we omitted to speak of these in their proper place, we shall introduce them here.

From the experiments of Achard and Hatchett, it appears that hair contains gelatine, to which it owes its suppleness and toughness. When hair is boiled in water, this principle is separated, and the hair becomes much more brittle than before. Indeed, if the process be continued long enough, the hair crumbles to pieces between the fingers. The portion insoluble in water possesses, according to Mr. Hatchett, the properties of coagulated albumen.

Mr. Hatchett has concluded, from his experiments, that the hair which loses its curl in moist weather, and which is softest and most flexible, is that which yields its gelatine most readily; whereas strong and elastic hair yields it with the greatest difficulty, and in the smallest proportion. This conclusion has been confirmed by a very considerable hair merchant in London, who assured him that the first kind of hair was much more injured by boiling than the second.

Vauquelin has published a curious set of experiments on human hair of different colours. He found it completely soluble in a Papin's digester. During this process, sulphuretted hydrogen was evolved. The solution thus obtained contains a kind of bituminous oil, which is deposited very slowly. This oil was black when the hair was black, but yellowish-red when red hair was the subject of experiment. When this oil was removed, nut-galls and chlorine produced copious precipitates. Silver was blackened, and acetate of lead precipitated brown. When concentrated by evaporation, it did not concrete into a jelly.

Water containing only four per cent. of potash dissolves hair, while hydro-sulphuret of ammonia is evolved. If the hair be black, a thick dark-coloured oil, with some sulphur and iron, remain undissolved. If the hair be red, this oil is yellowish. Acids throw down from this solution a precipitate, soluble in excess of acid.

Sulphuric and muriatic acids become red when first poured on hair, and gradually dissolve it. Nitric acid turns hair yellow, and dissolves it, while an oil separates, varying in colour, as before-mentioned, according to the colour of the hair employed. The solution contains a great deal of oxalic acid, besides bitter principle, iron, and sulphuric acid. Chlorine reduces it to a substance of the consistence of turpentine, partly soluble in alcohol.

Alcohol, digested on black hair, extracts from it two kinds of oil. The first, which is white, subsides in white shining scales as the liquor cools; the second is obtained by evaporating the alcohol. It has a greyish-green colour, and at last becomes solid. From red hair alcohol also extracts two oils, one white, as above, the other red as blood. After this latter has been extracted, the hair becomes chefnut. Hence its red colour appears to depend upon this oil.

Hair on incineration yields iron and manganese, sulphate and carbonate of lime, muriate of soda, and a considerable proportion of silica. The ashes of red hair contain less iron and manganese. Those of white hair still less; but in those we find magnesia, which is wanting in the ashes of other hair. The ashes of hair do not exceed .015 of the hair.

Hence, according to this analysis, hair consists of

1. Animal matters constituting the greatest part.
2. A white solid oil, small in quantity.
3. A greyish-green oil, more abundant.
4. Iron, state unknown.
5. Oxyd of manganese.
6. Phosphate of lime.
7. Carbonate of lime, very scanty.
8. Silica.
9. Sulphur.

Vauquelin infers from these experiments, that hair depends for its colour upon a kind of oil, which varies according to the colour of the hair in which it is found. He also supposes, that sulphuret of iron contributes to the colour of black hair. The sudden change of colour in hair from grief, he thinks, is owing to the evolution of an acid. Bichat, however, attributes this change, perhaps with greater probability, to the absorption of the colouring principle. To whatever cause it be owing, the fact appears undoubted; and it shews a closer connection between the living powers and the hair, than many physiologists are inclined to admit.

Wool appears, according to the experiments of Berthollet, to coincide almost exactly in its chemical properties with those of hair above-mentioned. When growing on the back of the animal, it is enveloped in a greasy matter, called the *yolk*, and which appears to be a kind of soap; or, more properly speaking, according to the experiments of Vauquelin, who has examined it, of

1. A soap of potash.
2. Carbonate of potash.
3. A little acetate of potash.
4. Lime.
5. A little muriate of potash.
6. An animal matter.

This substance appears to have the property of protecting the animal from insects to a certain degree, and of preserving

the softness of the wool, which are perhaps its chief uses. It is removed from the wool before it is manufactured, by the process termed *scouring*. The affinity of the animal matter of wool for all colouring principles is very great, and in general far exceeds that of the different vegetable fibres, as cotton, flax, &c. for such principles. There is one kind of coarse wool, however, which, according to Dr. Bancroft, does not possess this property, and receives colours with great difficulty. See DYEING, and the preceding article.

Wool, *Laws relating to.* The jealousy entertained on the subject of our wools, may be learnt from the legal restriction which has been made in relation thereto; as also with the view that as much employment as is possible may be found for the labouring classes. This is effected by the prohibition of the exportation of wool in an unmanufactured state, as will be seen below. It must be obvious, however, that it would be to little purpose to be thus strict respecting the article itself, if that which produced it was not equally guarded; therefore as early as 13 & 14 Ch. II. c. 18. it was made felony to export sheep from England or Ireland, or even to Scotland: now however the penalty is forfeiture of every ram, sheep, or lamb, and the vessel in which such is shipped with intent to exportation from Great Britain and the islands belonging thereto; and offenders are to forfeit 3*l.* for every sheep, &c. so shipped, and to suffer three months solitary imprisonment, and till the forfeiture be paid, but not to exceed twelve months; and for any second offence 5*l.* for each ram, &c. and six months imprisonment, and till the fine is paid, but not to exceed two years. 28 Geo. III. c. 38. § 2.

By the 9th and 37th sections, no wool, woollens, mortlings, yarn, or worked made of wool, woollacks, coverings, cruels, waddings, or other manufactures, or pretended manufactures slightly wrought up so that it may be reduced to wool again, or mattresses, or beds stuffed with wool combed or fit for combing or carding, may be shipped or exported, or carried or moved for that purpose, from Great Britain, or Guernsey, Jersey, Alderney, Sark, or Man, to any foreign place, on forfeiture of the wool, with the carriage, ship, or cattle on which it is laden or removed; but 300 sheep may be sent annually from Liverpool or Whitehaven to the Isle of Man (51 Geo. III. c. 50.); and the person offending to forfeit 3*l.* for every pound weight, or 50*l.* in the whole, and to be imprisoned three months, and till the penalty is paid, but not to exceed six months; but for a second offence he is to forfeit the like sums, and to be imprisoned for six months, and till such fine be paid, not exceeding two years; but this is not to extend to lambskins dressed for furs and linings.

And persons qualified by the governors of the following islands may export the respective qualities set against them from Southampton to those places in every year:

	Tons.
To Jersey - -	4000
To Guernsey - -	2000
To Alderney - -	400
To Sark - -	200

28 Geo. III. c. 38. § 16, 17. And 20,000 pounds weight of worked and woollen yarn may be exported annually from London to Lower Canada, by permission of his majesty in council. 47 Geo. III. c. 9. 52 Geo. III. c. 55.

By the 48 Geo. III. c. 44. wool may be shipped in England for exportation to Ireland, on being duly entered and bond given for its true exportation there; and upon obtaining a licence under the hands of the commissioners of the customs to allow it.

No wool shipped to be sent coastwise from one part of Great Britain to another, until due notice be given and bond entered into, and a licence obtained under the hand of three commissioners of the customs. Penalty, forfeiture. 28 Geo. III. c. 38. § 34. And wool must also be shipped coastwise in British ship, British owned and manned, the owner of which does not reside out of Great Britain. § 19. and 12 Car. II. c. 18. Formerly there were penalties and forfeitures for keeping or removing wool in Kent and Sussex within certain distances of the sea (ten and fifteen miles), without entry and bond, and procuring certificates or permits, and also for removing wool within five miles of the sea-coast of Great Britain before sun-rising and after sun-set; but by the 54 Geo. III. c. 78. all the regulations formerly required *antecedent to the removal* of wool on land throughout England are repealed.

Wool to be packed in packs, or trusses of leather, or canvas, called 'Pack-cloths,' or in linen or woollen, and to be marked 'Wool,' in letters three inches long, on forfeiture of the wool, and 1s. *per* pound. 28 Geo. III. c. 38. § 28.

Persons packing wool, &c. into boxes, barrels, casks, or chests, and other than as above, or pressing or steaming the same, to forfeit the goods, and 3s. *per* pound. *Ibid.* § 30, 31.

Insurances for the conveyance of wool contrary to this act void, and the parties may be punished. § 45, 46, 47, 48.

King's ships empowered and required to search ships for wool shipped without licence. § 49, 50, 51.

No person can seize wool unlawfully removing but officers of customs, excise, and salt-duties, or persons accompanied by a constable (§ 52.); and persons neglecting their duty to forfeit 20l., and making collusive seizures or agreements to be subject to like penalties as exporters. (§ 53. 55.) Hindering, obstructing, or beating officers, subjects offenders to transportation; and bribery of them, whether accepted or not, to the penalty of 300l. § 56, 57.

If any question arises upon the growth of the wool, the

onus probandi is to lie upon the owners. § 60.

Informations may be laid in any court of record, and penalties, &c. under 200l. may be determined before two justices of the peace; and justices at quarter-sessions may direct ships, goods, wool, &c. to be sold. § 62, 63.

Prosecutions to be commenced within three years. § 77.

Wool the growth of Ireland may be exported to England, and no where else. 1 W. & M. c. 32. 7 & 8 W. III. c. 28. 10 & 11 W. III. c. 10. 26 Geo. III. c. 11.

And the Admiralty is to appoint three ships of the sixth rate, and eight or more armed sloops, to prevent the exportation of wool from Ireland to foreign ports. 5 Geo. II. c. 21.

Wool the produce of any of the colonies, &c. in America, or countries on the continent of America, subject to any foreign European states, imported into certain British West India islands, may be imported into Great Britain under the regulations of the 12 Car. II. c. 18.

Those places are, Jamaica, Granada, Dominica, Antigua, Trinidad, Tobago, New Providence, Crooked island, St. Vincent, Bermuda, Caicos, Tortola, Curacoa, and the Bahamas. 27 Geo. III. c. 27. 45 Geo. III. c. 57. 47 Geo. III. sess. 2. c. 34.

British hare or coney wool may not be exported, (except to Ireland, 39 & 40 Geo. III. c. 67.) on penalty of forfeiture. The owner or shipper to pay 100l., and the master of the ship 40l. 24 Geo. III. c. 21.

WOOL, *Cheese made under*, in *Rural Economy*, a term applied to that sort of high-tasted ewe cheese which is made before the sheep are shorn. See CHEESE.

WOOL, *Pack of*, a quantity of wool packed up closely together in a large bag of the sack-cloth kind, which in London is constituted of two hundred and forty pounds. See WOOL.

Woollen Manufacture

WOOLLEN MANUFACTURE, *Progress of the.* The origin of the woollen manufacture, like that of many other useful arts, is not precisely known. At a very early period, domestic sheep were extensively spread over Western Asia. The introduction of sheep into Europe is not recorded by ancient writers, unless we suppose the expedition of the Argonauts to Colchis refers to this event. Sheep were probably first domesticated for their milk, and afterwards for their skins, which must have been the first dress of pastoral nations. Sheep and goats, in the early ages of society, were nearly of equal value. The Greeks, who ostentatiously refer all useful discoveries to their own country, and rank their inventors among the gods, have ascribed to Minerva the invention of spinning and weaving. These arts appear, however, to have been first practised, at a very early period, in Egypt, and applied to the spinning and weaving of flax. At what time they were first applied to wool is unknown. Though Pliny informs us, that Nicias of Megara discovered the art of fulling cloth, the property which wool possessed of felting was known in the East at a much earlier period, and probably gave rise to the first manufacture of woollen goods which were not woven, but felted like the substance of hats.

On this subject, Mr. Luccock, in his *Treatise on Wool*, judiciously remarks, " whilst the skins of sheep dressed with their wool on served as clothing, it is obvious that only one useful fleece could be obtained from one animal, and as the fleece is generally cast, or falls off once a year, this produce must have been wasted. In a very early period, however, the property which wool possesses of felting was discovered, or, in other words, it was found that by pressure and moisture the fibres of wool might be made to adhere together, and produce a compact pliable substance, quite as durable and more convenient than the skins formerly used. This appears to have been the first effort to produce a woollen manufacture." It is probable the felting property was discovered by accident, as some fleeces will felt upon the sheep's backs; among farmers, these are called cotted fleeces. When the application of this discovery was first made, the knowledge of the art was soon widely spread. The tents of the Arabs and Tartars are, at the present day, all made of felt from the wool of sheep, mingled with the hair of goats, camels, and other quadrupeds, and may be considered as remains of the original art of cloth-making.

The art of spinning and weaving threads made from wool was, in all probability, derived from the East; they are alluded to by Moses as existing nearly fifteen hundred years before the Christian era, and it appears that the early patriarchs had numerous flocks of sheep.

The greater part of these sheep, we are informed, were, at first, either dark-coloured or spotted; hence we may infer that the art of dyeing wool was then unknown. When the selection and cultivation of white wool gave to woollen cloth the property of receiving the tints of the dyer, the value and use of wool must have greatly increased, owing to the great estimation in which richly-coloured garments are held by people advancing to a state of civilization.

Thus, in addition to the superior pliability and comfort of woollen cloth, compared with skins or felts, the taste for it must have been widely spread by the art of dyeing. It had also the great recommendation to its general adoption, that it could be fabricated with ease in every family. The

machinery required for the purpose was extremely simple. The distaff and the loom, says Mr. Luccock, were little more in the hands of the first manufacturers, than the spade in those of the husbandman. Spinning and weaving, as we have already observed, were in use at least fifteen hundred years before the Christian era; but the manner in which they were performed is not related until about three centuries afterwards. Then the loom consisted of a frame of wood, in some respect different from the modern one, but well adapted to the same purposes.

The alterations which have been made in it consist, perhaps, more in the position of the beam, and the mode of opening the web for the passage of the shuttle, than in any other circumstance. Nor was the earliest mode of spinning less perfect, than that which was practised in the most celebrated manufacturing countries for many ages afterwards. It was performed by means of a rod or staff, about which the wool to be spun was carefully wrapt, and held in the left-hand, while a rough kind of spindle, quickly twirled betwixt the right-hand and the thigh, was suffered to continue its motion when suspended by the thread which the artist gradually lengthened with his fingers. This least complex of spinning-machines is not entirely laid aside even now. A few years since it was not uncommon in the county of Norfolk, and its continuance in use through so many ages is the best proof of its excellence.

The preparing of wool for spinning was probably first effected by the fingers, and afterwards by the fuller's teazle or thistle, the *diplacus fullorum*, which with its rough and hooked points was well adapted to the purpose, and has continued in use to the present day. The card afterwards used was probably a substitute for the *carduus*, or teazle. The application of the wheel to a spindle, or the spinning-wheel, is, we believe, unnoticed in history. Whenever these inventions took place, it is probable their first introduction contributed more to increase the quantity, than improve the quality of the yarn and cloth. For a considerable period after the commencement of the woollen manufacture, the improvements made in spinning or weaving of wool were effected by the improved address and skill of the manufacturer, rather than by any alteration in his machinery, as we now see the manufacturing nations of the East execute very elaborate works with instruments of the most simple construction. In proportion as luxury and refinement increased, the demand for superior fabrics would induce the growers of wool to pay great attention to the fleece, and to select and preserve for breeding those sheep which produced the softest and finest wool; with the ancients these terms were synonymous. The produce of fine white wool from sheep is entirely the result of cultivation; it has never been grown except in countries where the woollen manufactures have flourished. The race of fine-woolled sheep has, however, been partly preserved in those countries after the destruction of their trade. The grower would also soon learn to pay particular attention to the whiteness of his fleeces, as a clear white ground is necessary for receiving the most brilliant dyes. Blue, purple, and scarlet, were the tints most admired; and though the ingredients, by means of which they were produced, are in some measure unknown, yet we have the most indubitable testimonies to their excellency, and the estimation in which they were held. To produce them in their richest

lustre, a selection of the wool most adapted to receive them must be made, and this would operate with great precision upon the wool-forter's attention.

While the manufacture of wool was confined to the houses of the grower, and the business of it transacted by his domestics in a secluded state, there was less room for the stimulation and exercise of invention than in after-ages, when it became the appropriate calling of one particular part of the community, and their success depended upon the opinion which others formed of the fabric. Yet in the simplest days of Greece, it was not deemed an employment unsuitable to palaces, nor did a princess degrade her dignity by superintending the labours of the loom, the distaff, and the dyeing vat.

We have little information respecting the woollen manufactures of the Greeks and Romans, as distinct from their domestic manufactures; but large establishments were necessary for the clothing of distant armies, and for foreign commerce. That the Romans had carried the manufacture of fine woollen cloth to a high degree of perfection, is proved by a variety of circumstances, and particularly by the great attention paid to the cultivation of fine-woolled sheep, and by the high prices at which the wool and sheep were sold, as appears from the writings of Pliny, Varro, and Columella. Pliny describes two kinds of sheep: the one which grew coarse long wool, and was on this account called *hirtum* or *hirsutum*, and from its hardness and ruder treatment *colonicum* or rustic; the other breed was called *molle*, from the softness of the wool, and *generosum* or noble, from its excellence; also *pellitum*, from its being clothed with skins to protect the wool. The race is sometimes also called Tarentinum, Apulum, Calabrum Atticum, and Græcum, from the neighbourhood or district in which it chiefly lived; but what is of more importance, as shewing the origin of the fine-woolled sheep of Italy, the race is called Asianum; and, according to Pliny, a similar race existed in his time at Laodicea in Syria. The description given of these sheep by Pliny agrees with the present race of Merino sheep. There is not, says Dr. Parry, throughout Europe, any breed of short-woolled sheep now existing besides the Merino, of which the males are horned and the females not.

That the Romans imported their Tarentine sheep into their western colonies, with the art of manufacturing fine cloth, we learn from Strabo and Pliny. The former writer, who flourished in the reign of Augustus, says, that in Turdetania in Portugal, then a part of Spain, "they formerly imported many garments, but now their wool was better than that of the Coraxi, and so beautiful, that a ram for the purpose of breeding was sold for a talent, and that fabrics of extraordinary thinness were made of this wool by the Saltratz." Probably this was similar to the shawl cloth of India, and woven in the same manner, as Pliny calls it *scutulatus*, a term which he applies also to the spider's-web. The little attic talent of silver is estimated to equal in value 216*l.* of English money, which shews the high estimation in which the best wool was held even in the colonies of Rome.

All ranks of people of both sexes among the Romans chiefly wore woollen garments. In the reign of Aurelian, 270 years after Christ, a pound of silk, according to Vopiscus, was equal to a pound of gold. A people so pre-eminent in wealth, and in all the refinements of art, would naturally be solicitous to attain the highest degree of excellence in the manufacture of those fabrics, which were calculated to gratify their passion for adorning their persons, and it was equally as necessary to consult their ease as

their vanity. The summer-heat of Italy was so great, that the affluent could scarcely have supported a woollen dress, had it not been made of the lightest and thinnest cloth. We find also, that during the Augustan age, and for a considerable time afterwards, it was the fashion to wear cloths which, as at present, were furnished with a raised nap or pile. Such cloths were called *pexæ*, in contradistinction to *tritæ* or thread-bare. Thus Horace:

"—— Si forte subucula pexæ
Trita sub est tunica — rides."

"You laugh if you espy a thread-bare vest
Under a well-dressed tunic."

And also Martial:

"Pexatus pulchre, rides mea, Zoile trita."

The term *pexatus*, applied to cloth, leads us to suppose that the nap or pile was raised with a comb, having very fine teeth. Pliny informs us, that in his time the price of wool had never exceeded 100 sesterii the libra, or pound; now the Roman sesterius being about 8*d.* of our money, and the libra about 5245 grains, it follows that an avoirdupois pound, or 7008 grains, would have cost about 1*l.* 2*s.* of our money. From the intercourse with Persia and the East, the Romans would become acquainted with the shawl-cloths of India, and would naturally wish to imitate so beautiful and delicate a fabric. These are made from very soft fine short wool, and not from combed wool, as has been generally supposed in this country. The existence of that manufacture in Hindoostan for many ages, is a proof of the high degree of perfection to which the fabrication of woollen cloth had been carried in former times. For shawl-cloth is only woollen cloth, woven with a twill, and unmilled, but it is spun to a great degree of fineness, and from wool so peculiarly soft, that it has never been rivalled by any European nations. The perfection of the colours, and the skill displayed in the weaving, we have no reason to believe are greater now than in the time of Alexander the Great; and if these manufactures were successfully imitated by the Greeks or Romans, or even distantly approached in the manufacture of their fine cloths, we may form some idea of the perfection to which they had arrived. When in the decline of the Roman empire, their colonies were overrun by savage barbarians, all their public establishments and manufactures were destroyed, but the art of producing from the fleece a warm and substantial clothing was never entirely lost, even during the darkest days of ignorance. It began to revive, and became the separate occupation of one class of the community about the middle of the tenth century in the Low Countries, where it remained the glory of the people, and the source of their opulence, through more than four hundred years. The wool which it consumed for the first few years was the produce of their own pastures, which had but lately been reclaimed from the forest; but as the manufacture extended itself, the demands became larger, and were supplied from a greater distance. The wealth which it distributed was soon visible, and people crowded into the country, engaged in its commerce, and pushed their speculations with increasing vigour through a hundred and fifty years, when an inundation of the sea threatened to involve the art, the artist, and the country, in one general destruction. The dispersion of the people who fled from the calamity which appeared to overwhelm their hopes, instead of destroying the infant manufacture, gave it additional vigour, and was the means of establishing a connection be-

tween the Netherlands and foreign countries, which proved of the highest importance to commerce. It contributed to a much more speedy recovery of the arts connected with the woollen manufacture, from the ruin which seemed to threaten them, and gave a striking instance of their partiality for the seats where they have once flourished, under the patronage of a government liberal enough to encourage, and sufficiently powerful to protect them, even in situations attended with natural disadvantages. The influence of these manufactures upon the fleeces of the Low Countries must have been very considerable; for before the year 960 we have no reason to suppose that their quality was superior to that which we find in the neighbouring districts; yet it was not very long ere Flanders and Brabant became famous for the manufacture of fine cloths, even at a period when they imported but little foreign wool. Perhaps the fabrics might not be equal to those which we now produce from the fleeces of Spain, or even from the improved ones of our own sheep, but they were preferable to those of England and the nations of the continent, Italy and Spain excepted. It was about the year 1200 that the merchants began to import the wools of other countries, to extend their connections much more widely, and to grow by this means still more rich and powerful. The manufactures required a larger quantity of the raw material than usual, and the population of the country had reached that extent which does not admit of a great number of sheep being kept, even though the employment of the people depend upon the fleeces, and their subsistence upon the food which they furnish. We shall observe instances of a similar kind when we treat more particularly of England. The operation of these two causes was evidently sufficient to induce the manufacturer to go farther from home, and to seek the most convenient methods of supplying his looms. It might have been expected that he would have turned his attention to France and to Germany; but independent of the hostile dispositions of some of the neighbouring sovereigns, the raw material was too bulky to be conveyed at an easy expence through the bad roads of a half cultivated country; and the ships of Spain and of Britain, who found an interest in supplying the wants of the Netherlands, unladed their cargoes almost at his very door, and solicited in payment but little else than the goods which he had manufactured.

Spain was the first country on the western side of Europe, where the Tarentine breed of fine-woolled sheep were cultivated with success by the Romans. See SHEEP.

This breed, intermixed with the native flocks, gave rise to the present fine-woolled sheep of Spain; and it does not appear that this valuable race was ever greatly neglected in that country. That it abounded in sheep in what is called the middle age cannot be doubted. At the period when the Saracens extended themselves in Spain, about the eighth century, to use the quaint words of Roderic, archbishop of Toledo, "it was fruitful in corn, pleasant in fruits, delicious in fishes, savoury in milk, clamorous in hunting, and gluttonous in herds and flocks,"—*guloſa armentis et gregibus*. He wrote in A.D. 1243. In England at that time sheep were so scarce, that a fleece was estimated at two-thirds the value of the ewe which produced it, together with the lamb.

Into Spain the invaders either carried the arts of luxury, or, what is more probable, improved them by their superior industry. The revenue of one of their sovereigns in the tenth century amounted to six millions sterling; a sum, says Gibbon, which at that time probably surpassed the united revenues of the Christian monarchs. When, several centuries afterwards, the Saracens were gradually expelled by their

Christian neighbours, Spain saw nothing but the change of religion to compensate the loss of population, of agricultural and mechanical science, of industry, and wealth. On the recovery of the Seville from the Moors in 1248, not less than 16,000 looms are said to have been found in that city. Of these, the greater number was probably employed in the fabric of woollen cloths. According to Uftarix, "Theory and Practice of Commerce," the manufactures of Segovia flourished most, both in point of number and quality, and were in high esteem, being the best and finest that were known in ancient times. The temperature of the climate, and the luxurious propensities of the inhabitants, would naturally determine these fabrics to be of the lightest and softest kinds. Hence in the midst of the boasted ancient manufactures of England, we read only of two or three instances of the importation of English cloth into Spain. The Spaniards had certainly at that time their own native fleeces best adapted to their own taste and climate.

We are told by Dillon, in his "History of Peter the Cruel," that the woollen cloths of Barcelona were in high esteem in Seville in the reign of that prince, and in the preceding century. So far back as 1243, the woollen cloth of Lerida is spoken of in terms of great estimation. A few years after, Baurias, Valis, Gerena, Perpignan, and Tortosa, were remarkable as manufacturing towns, and for the fineness of their cloths, fustians, and serges. So great was their exportation, that in 1353 there were 935 bales of cloth taken on board a ship from Barcelona to Alexandria by a Genoese privateer; and 1000 bales of cloth were taken on board three Catalonian ships in 1412, by Antonio Dorco, in the port of Callus. We are told by the same author, that, according to records still extant in Barcelona, considerable orders for wool were sent to England in 1446, in order to be manufactured there and returned to England in the form of cloth, the Spaniards themselves disdaining to wear it.

According to Lucius Marineus Siculus, who wrote in the time of the emperor Charles V., Spain was then full of herds and flocks, more especially it contained innumerable sheep; so that many shepherds, whom he knew, had flocks of 30,000 each; on which account Spain not only supplied its own people most abundantly, but also foreign nations, with the very softest wool.

This account is confirmed by what is related by Sandoval, who states, that in an insurrection in Spain in 1519, the army of insurgents, among whom were many cloth-workers, stipulated, among other points, that the cloths imported into Spain should be of the same size and goodness as those wrought there; and that the merchants and clothiers might have leave to seize, in order to work up, half the wools sold for exportation, paying the owners the price at which they had been bought. Hence we learn the superiority of Spanish cloth, and the great sale of Spanish wool to foreign countries at that time.

Damianus a Goes, who was page to Emanuel, king of Portugal, in 1516, has written a short account of the memorable things of Spain, which he dates at Louvain in the year 1541. In this work he says, that there are annually exported from Spain to Bruges 40,000 sacks of wool, each selling at the lowest for twenty gold ducats.

Now from an authentic acquittance, preserved in the Fœdera, from queen Elizabeth to Cosmo de Medici, for a sum borrowed by him of Henry VIII., we find that the gold ducat or florin was in 1545 equal to five shillings of our money. In this year, the 36th of Henry VIII., the base coinages began; but as queen Elizabeth seems to have continued receiving the instalments of the Florentine debt

for several years at the same rate, when the shilling was of something more than the present value, we think it probable that the rate was fixed at the beginning of the year 1545, when the shilling was at 1*s.* 1½*d.* of our present coin. This wool was, therefore, worth at least 5*l.* 14*s.* 7*d.* the sack of 181½ lbs., and 11*l.* 9*s.* 2*d.* the sack of 364 lbs.

In 1560, in the time of Guicciardini, Spanish wool in the Netherlands was at a somewhat lower price. He tells us, "that they used formerly to send annually from Spain to Bruges more than 40,000 sacks, but that in this year the Spaniards, having made more cloth at home, had sent only 25,000 sacks, at 25 crowns each." The crown being 4*s.* and the shilling 1*s.* 4½*d.* of our money, this would be 10*l.* 1*s.* 1*d.* the sack of 364 pounds. The depreciation seems in truth to have arisen from a diminished demand for this wool in the Netherlands. The wools imported into the Netherlands from Spain were the lower or coarser kinds.

The superfine wools of Spain seem to have been first introduced among the Italian states. Thus Damianus a Goes in 1541, after having specified the 40,000 sacks to Bruges, as before-mentioned, adds, "and also to Italy, and other cities of the Netherlands, are annually sent about 20,000 sacks, of which those used in Italy, being of the choicest wool, are sold at from forty to fifty gold ducats each."

From this account, we have a fair opportunity of drawing two important inferences: the first is, that the Spanish wool which went to the Netherlands was, as we have before observed, of the coarsest kind, being of only half the price of that which was exported to Italy; secondly, we can compare the value of the latter with that of our English wool, the best of which, according to the act of parliament in 1534, already quoted, did not in England exceed 5*s.* the stone of 14 pounds, of 6*l.* 10*s.* the sack of 364 pounds. The shilling, however, being then equal to 1*s.* 4½*d.* of our coin, increases the price of the sack 8*l.* 18*s.* 9*d.*; to which add custom and subsidy, 3*l.* 13*s.* 4*d.* or 5*l.* 0*s.* 10*d.*, and the result will be 13*l.* 19*s.* 7*d.* The additional charges of freight and merchant's profit would scarcely bring the whole amount to 16*l.* 16*s.* On the other hand, according to the testimony of Damianus a Goes, the Spanish sack of 181½ pounds was in 1541 worth 14*l.* 6*s.* 5½*d.*, and the sack of 364 pounds 28*l.* 14*s.* 6*d.* of our present money. If the author speaks only of the value of this wool in Spain itself, then a farther addition must be made of freight, merchant's profit, and probable duty to the crown. On the whole, this calculation is sufficient to shew in the strongest light the superior price of superfine Spanish wool, to that of the very best at that time produced in Britain.

Next in order of time to the Italians, the manufacture of superfine wool seems to have been adopted by the French, who, according to Guicciardini, in 1560 sent by land to Antwerp some very fine cloths of Paris and Rouen, which were highly prized.

It is probable, however, that these cloths were made only of mixed wool.

A strong confirmation of the early use of the best Spanish wool, unmixed with coarser by the Italian states, is furnished by Richelieu's Political Testament, printed in 1635, in which, speaking of the fine woollen manufactures of France, the author says, "the Turks prefer the draps de sseau de Rouen to all others, next to those of Venice, which are made of Spanish wool."

And the author of "England's Safety in Trade's Increase," written in 1641, tells us, that "the greatest part of their (the Venetians) wools from Spain, and the rest from Constantinople, is commonly brought in English shipping."

In 1646, Nicholas Cadeau and other Frenchmen had letters patent for twenty years, for making at Sedan black and coloured cloths, like those of Holland, of the finest Spanish wool.

The inhabitants of the north of Europe, as before-mentioned, were not at first able to manufacture fine Spanish wool, without the assistance of that which was longer and coarser. But what in the beginning was a matter of necessity, became afterwards an object of choice; and the more skilful clothiers, whether in Holland or elsewhere, either carding the finer and dearer Spanish with the coarser and cheaper English, or forming a warp of the latter, which they covered with a woof of the former, contrived to make a cheap and serviceable cloth, which pleased the eye equally well with the more costly fabrics of entire Spanish wool. This though generally concealed with great care at the time, yet is afterwards candidly acknowledged by writers actually engaged in the commerce of wool, and sufficiently refutes the prejudices which had here prevailed from the middle of the 16th to the middle of the 17th century. Hence it appears that our wool, when placed in connection with Spanish, was chiefly valuable from being well calculated not to improve but to adulterate it.

A treaty between France and Spain in 1659, enabled the former freely to obtain the wool of the latter, and thus to gain great advantage over us in the Levant trade. From the proximity of France to the woollen manufactures in the north of Spain, it might have been expected that the French would have earlier engaged in this manufacture; but owing to their frequent northern wars, and their attention being directed to the manufacture of silk, the French do not appear to have commenced the fabrication of woollens for exportation extensively before the 16th century. About this time, France made great progress in her manufactures of wool, and in securing the export trade, particularly that to Tartary, for which she was better situated than Holland or England.

The nature of her trade to warm climates directed her attention to the fabrication of finer and lighter cloths, than those made by her northern neighbours; in consequence of which she preserved the greater part of the Turkey trade to the period of the French revolution, and in general fine French cloths had attained a celebrity for their superiority, both in texture and dye, over those of any other country in Europe. The native breeds of sheep in France were greatly improved by intermixture with sheep imported from Spain. With these advantages, France might have nearly secured a monopoly of the finer branches of the woollen manufacture, had not the absurd policy of her rulers, in the revocation of the edict of Nantz, driven the manufacturing Protestants to other countries, where they contributed, by their exertion, their skill, connections, and capital, to form establishments which rivalled those of the country from which they were expelled.

Notwithstanding this, as France supplied the greater part of her own population of twenty millions with cloth, besides her foreign exports, we conceive that the woollens manufactured in that country, before the late revolution, equalled in quantity the cloth made in England at the time, and greatly exceeded it in value. Under the emperor Napoleon, the best Merino flocks were imported in multitudes from Spain, which have spread over the country, and are equal to supply extensively her manufactures of woollens, when they shall be again fully established. Considerable quantities of fine wool have been imported from France into England since the peace of 1815.

The confusion attendant on a great revolution, continued for twenty years, gave so severe a blow to the manufacturing establishments of France, that a considerable time must elapse before they are completely established. Prior to this revolution, the superfine cloths of France were superior to those of England, in texture, colours, and softness. In the finer articles of worsted goods, and in the mixed worsted goods made partly with long combing-wool, and partly with silk or goat's-wool from the Levant, they surpassed the manufactures of this country; but the manufacturers of the commoner kinds of worsted goods, as tamies and shalloons, could not rival us in foreign markets for want of a proper supply of wool suited to the purpose. The following were the principal seats of the superfine and fine woollen manufactures in France, arranged according to the different qualities of the goods made at each, beginning with the finest:

1. The manufactures of Gobelins.
2. Of Sedan.
3. Of Abbeville.
4. Of Louviers.
5. Of Elbœuf.
6. Of Rouen and Darnetal.

Besides several detached manufacturing establishments of superfine cloth in Languedoc, Champagne, and other parts of France.

At the Gobelins, superfine cloths of the very first quality were manufactured; but the manufactures there were confined solely to the broadest white cloth intended to be dyed scarlet or purple, and the brightest colours from cochineal.

Sedan followed next to Gobelins for the beauty of its superfine cloths, where they were also made of various breadths and colours.

Abbeville may be placed next after Sedan: some have even supposed that it equalled Sedan in the fineness of its cloths; but this arose from the cloths of the latter place being of various sorts: the lower kinds were certainly inferior to those of Abbeville; but the quality of the greater part of the cloths of Sedan were of a better kind than the average quality of the cloths of Abbeville. In the manufactures of Sedan, each manufacturer confined himself to a particular kind of cloth, for which he became distinguished, some being celebrated for fine, and others for superfine cloths exclusively; whereas in Abbeville, Louviers, and the other districts enumerated, there were manufacturers who made various sorts, and the proportion of the fine to the superfine was greater than at Sedan.

Elbœuf was one of the most ancient seats of the woollen manufacture in France, but the quality of the cloths made there had greatly degenerated from the years 1760 to 1770; but afterwards the manufacturers returned to the former quality of their cloths, which were partly made of the fine wools from Berry, and partly from fine Spanish wool, or from a mixture of Spanish with the best wools of Berry.

Rouen and Darnetal may be placed in the sixth class of manufacturing districts of fine cloth, in which the finest wools of France were principally used, mixed with those of Spain.

The establishments for the manufacture of common cloth and coarse woollens were much more widely spread over France. The goods appear to have been principally consumed in that country to supply the demand of a population of twenty millions, and the numerous military establishments, besides what might be sent to the French colonies.

As the French never exported any considerable quantity of common or coarse woollen cloths, the manufactures of these articles never equalled in extent those of England. The circumstance of the coarse cloth manufacture being so widely spread over the country, tended also to prevent that degree of rivalry which promotes the spirit of improvement where manufactures are more concentrated; add to this, the French had not that abundant supply of the coarser clothing-wools which could enable them to rival us in the export of heavy woollen goods.

The worsted manufactures of France, including *serges* and those goods made with a warp of worsted, were principally carried on in four of the provinces of France, but more extensively in Picardy than elsewhere. The long combing-wools which supplied this manufacture, were partly the produce of France, and partly imported from Holland, England, Flanders, and Germany. M. Rolland, in the French Encyclopædia, describing the French manufactures in the year 1783, soon after the American war, says, that during that war the English administration tacitly encouraged the exportation of wool to promote the interests of agriculture. He describes the French combing-wool as being coarser and more harsh than the wool of Holland, as wasting much more in the manufacture, and making goods of a very inferior quality. The combing-wools of England, though generally less sound and fine, and of a less pure white, than those of Holland, were particularly well suited to some parts of the worsted manufacture.

The combing-wools from Germany were coarse and harsh, and only used in default of other supplies. Very fine worsted yarn was also obtained from Saxony and the environs of Gottingen; but this yarn was tender, and required to be mixed with worsted yarn from English or Dutch wool. The yarn of Turcoign was supposed to be Dutch, but was principally from Flanders and Artois. The goat's-wool came from the Levant, by way of Marseilles, in bales of from 200 to 300 lbs. It sold from four livres to twelve livres *per* French pound; the price of that most generally used was about 4 livres 10 sous *per* pound. The silks used in silk camelots, &c. were obtained from Paris and Lyons.

The following table gives the quantity and value of wool yarns and worsted pieces in Picardy; but he supposes the quantity to be under the real amount, the manufacturers concealing the extent of their trade to avoid arbitrary taxation.

Wool consumed in the Worsted Manufactures of Picardy.

		sous.	livres.
French wool	3200000 at 22		3520000
Dutch ditto	180000 at 40		360000
English ditto	200000 at 32		320000
German ditto	100000 at 22		110000
	3680000		4310000

Yarn imported.

		liv. s.	
Yarn of Turcoign	60000 at 8 10		510000
German yarn	100000 at 7 0		700000
Levant yarn, or mohair	220000 at 5 10		1210000
Silk used in fine worsted goods	20000 at 35 0		700000
Total value of wool and yarn	- -		7430000
	4 M 2		

Brought forward	-	-	7430000
Combing and spinning 3680000 lbs. of wool	4310000		
Winding, warping, and weaving	-	-	4770000
Dyeing of yarn and pieces	-	-	190000
Profit of the wool-dealers, manufacturers			1300000
Total value of 150000 pieces coming from the manufacturer	-	-	18000000
Value of dyeing-wares	-	-	500000
To which carriage and profit of the merchant and draper	-	-	2000000
Total value of worsted goods in Picardy			20500000

One million and fifty thousand pounds weight of wool were also consumed in hosiery in the same province, of which the greatest part was native; and the remainder about two hundred and fifty thousand pounds weight from Holland. The number of working manufacturers in Picardy is thus stated:

50000 men who gain 140 livres per annum	7000000
50000 women 70 -	3500000
150000 children 40 -	6000000

The greater part of the manufacturers resided in the country, and were employed part of the time in agriculture; this was also the case with the manufacturers in the towns, so that not more than eight months in the year were devoted to manufactures. This change of employment, so conducive to the health and comfort of the labouring classes, may be regarded as presenting the happiest form under which manufactures can be carried on. This was also in a considerable degree the situation of the woollen and worsted manufacturers in Yorkshire, before the late introduction of machinery had driven the population into large factories; a change which may be regarded as one of the greatest evils that ever afflicted civilized society, tending directly to degrade and enfeeble the human race, and to render man a wretched machine, a prisoner from the cradle to the workhouse or the grave, devoid of moral feeling and physical energy.

What was the extent of the worsted manufacture in the other provinces of France where it was carried on, we have no correct means of ascertaining. In the middle of the last century, the export of cloths and worsted goods from Languedoc alone amounted annually to about 60,000 pieces, sent to the Levant and to Barbary. At that time also, Spain, and all the countries bordering the Mediterranean, received worsted goods from France. In the variety of worsted articles, in the ingenuity of the patterns, and the superiority of the workmanship, as well as of the dyes, France may be regarded as having surpassed any other nation in Europe, prior to the year 1780, or about the close of the American revolution. Since that period, the manufactures of England have astonishingly increased, and have obtained a decided preference in foreign markets.

The woollen manufactures of Saxony and Germany have been long established; the fugitives from the edict of Nantz contributed much to improve and extend them. During the late war, all the manufactures in Germany and every part of the European continent suffered greatly, but are at present rapidly reviving, and will abridge the amount of our exports in Europe.

In Russia, Sweden, and Denmark, the woollen manufacture, as a distinct occupation, is comparatively new; yet it has existed long enough to produce great alteration

in their flocks. And as this change was attempted in a more enlightened period, and conducted by scientific men, the best means were adapted to promote the improvement, and new breeds of sheep have been introduced into both countries. The same remark applies to Saxony and other circles of the German states, and even Hungarian flocks are not without evident indication of a change for the better.

Of the worsted manufacture as distinct from the woollen, we have little information respecting its origin. It comprises all those goods made of combed wool in distinction from carded wool. We are unacquainted with the period when the wool-comb was invented, or when worsted goods were first manufactured. It is probable, that worsted goods were originally woven in the East, and that the knowledge of them was brought into Europe either by the Armenian merchants, or those who returned from the extravagant expeditions which were undertaken for the recovery of the Holy Land from the dominion of the infidels. The garments which are now worn by the Turks, some of which seem to have been produced by means of the comb, the incidental mention of that instrument in an account which we have of Angora, and the demand for worsted goods through the Levant, confirm the conjecture, and lead us to suppose, that there exist very considerable manufactures of this kind in the Turkish empire, although we know little more of its domestic and rural condition, than can be obtained from the most vague accounts and uncertain deductions. After the art of spinning worsted yarn was known in the west of Europe, the looms of the Netherlands became active in converting it into those peculiar kinds of goods to which it was adapted, and it seems as though the distinction between these and woollen articles was not generally noticed until some years afterwards. It might have been expected from the nature of the article, that the manufacture of worsted goods should in many southern countries have preceded that of cloth. Long-stapled wool suited to the comb seems more spontaneously the produce of uncultivated sheep, than short wool, which is to be manufactured by carding, and its mode of manufacture more nearly resembles that of flax; hence it is not improbable, that worsted goods were made in Egypt and the East before the manufacture of woollen cloth. This is, however, uncertain.

In the manufacture of long wool, the fibres are arranged parallel to each other, like those of flax; but before they are spun, they require to be laid even by some kind of instrument, which shall separate the fibres, that they may draw out easily in spinning. A comb of a very simple construction, with a few wires for the teeth, was probably first made use of. It was afterwards found, that the application of heat to the comb contributed more effectually to the regular arrangement of the fibres; and thus the invention of the common wool-comb arose, but at what period is unknown. Vulgar tradition ascribes the invention to bishop Blaize, who first used it in Alderney; but there does not appear any authority in support of this opinion. The bishop lived in Armenia, and was raised to the episcopal dignity about the time of Dioclesian, and suffered martyrdom under that tyrant. Before he was beheaded, he was tortured with iron combs, with which his flesh was torn; and hence when an instrument of that kind was brought into common use, the workmen chose him for their patron saint. The traditions of the origin and progress of the worsted manufacture are thus extremely imperfect; we shall have occasion to speak of its introduction and progress in this country in the following section.

Rise and Progress of the Woollen Manufactures in England.—The Romans, as we have stated on the authority of Camden, had a cloth manufacture at Winchester. The first account of any distinct body of manufacturers afterwards occurs in the reign of Henry I., but either the people of this country were wholly clothed in skins or leather in the intervening space, or, what is more probable, coarse cloths were manufactured in a rude manner in most of the towns and villages in England. A great part, however, of the dresses of the labouring classes in the country was made of leather, particularly the breeches and waistcoats, even till the present reign. George Fox, the founder of the Quakers, in the reign of Charles I., travelled on his missions through the country, buttoned up in a leathern doublet, or waistcoat with sleeves, which supplied the place of a coat. This was not, as his adversaries afterwards affirmed, from any superstitious prejudice respecting that costume; it was the common dress of the labouring mechanics at that time, to which class he belonged.

The first account of any foreign weavers settled in England is recorded by William of Malmesbury and Giraldus Cambrensis, who relate that a number of Flemings were driven out of their own country, by an extraordinary encroachment of the sea in the time of William the Conqueror. They were well received, and first placed in the neighbourhood of Carlisle, and on the northern frontier; but not agreeing with the inhabitants, they were transplanted by Henry I. into Pembroke-shire. They are said to have been skilful in the woollen manufacture, and are supposed to have first introduced it into England as a separate trade. Cloth-weavers are mentioned in the exchequer accounts as existing in various parts of England in the reign of Henry I., particularly at London and Oxford. The weavers of Lincoln and Huntingdon are represented as paying fines for their guild in the 5th of Stephen; and in the reign of Henry II. (1189), there were weavers in Oxford, York, Nottingham, Huntingdon, Lincoln, and Winchester, who all paid fines to the king for the privilege of carrying on their trade. (*Chronicon Pretiosum*, p. 64.) There were also cloth dealers in various parts of York-shire, Norwich, Huntingdon, Gloucester, Northampton, Nottingham, and Newcastle-upon-Tyne; also several towns in Lincolnshire, and at St. Alban's, Baldock, Berkhamstead, and Chesterfield, who paid fines to the king that they might freely buy and sell dyed cloths. These are supposed to have been cloths imported from the Flemings. The red, scarlet, and green cloths, enumerated among the articles in the wardrobe of Henry II., were most probably foreign, as the English had attained little skill at that time in the art of dyeing. Madox's *History of the Exchequer*.

In the 31st of Henry II. the weavers of London received a confirmation of their guild, with all the privileges they enjoyed in the reign of Henry I.; and in the patent he directed, that if any weaver mixed Spanish wool with English in making cloth, the chief magistrate should seize and burn it. (*Stowe's Survey of London*.) This absurd edict was issued under the pretext of the inferiority of the Spanish wool, but was doubtless intended to encourage the growth of English wool, an article from which our kings derived a considerable revenue. The circumstance rather proves the superior excellence of Spanish wool at that time, and the jealousy which its importation had excited among the English wool-growers.

In the reign of Henry III. an act was passed limiting the breadth of broad-cloths, russets, &c. to two yards within the lifts. In the year 1284, foreign merchants were first permitted to rent houses in London, and buy and sell their

own commodities, without any interruption from the citizens. Previous to this date they hired lodgings, and their landlords were the brokers, who sold all their goods, and received a commission upon them. It was soon after pretended that the foreign merchants used false weights, and a clamour being raised against them, twenty of them were arrested and sent to the Tower. Amidst the numerous absurd restrictions to which commerce and manufactures were subjected, we need not be surprised at the little progress which they made.

The materials which history affords respecting the woollen manufacture before the reign of Edward III. are but scanty; it appears that the office of aulnager, or cloth inspector, was very ancient. In the reign of Edward I. we are informed by Madox, that Peroult le Tayleur, who held the office of aulnager of cloth in the several fairs of the realm, having forfeited it, the king, by writ of privy seal, commanded the treasurer to let Pieres de Edmonton have it, if he were fit for it, and a writ was made out accordingly, and he took the oaths of that office before the treasurer and barons. The facts above-stated prove the existence of the cloth manufacture in England before the time of Edward III., who is generally supposed to have first introduced the art into the kingdom. There is no doubt, that a new impulse was given to it during this reign by the liberal protection granted to foreign manufactures here: in all probability, they first introduced the manufacture of stuffs from combed wool or worsteds; an art requiring more skill, and more complicated processes, than are employed in the making of cloth.

In the year 1331, John Kemp, a master manufacturer from Flanders, received a protection to establish himself here with a number of dyers and fullers to carry on his trade, and in the following year several manufacturers came over from Brabant and Zealand. It is said, that the king's marriage with the daughter of the earl of Hainault enabled him to send over emissaries without suspicion, to invite the manufacturers to this kingdom. These manufacturers were distributed over the country, at the following places:—The manufacturers of fustians (woollens) were established at Norwich, of baize at Sudbury in Suffolk, of sayes and ferges at Colchester in Essex, of broad-cloths in Kent, of kerries in Devonshire, of cloth in Worcestershire and Gloucestershire, of Welsh friezes in Wales, of cloth at Kendal in Westmoreland, of coarse cloths, afterwards called Halifax cloths, in York-shire, of cloth in Hampshire, Berk-shire, and Sussex, and of ferges at Taunton in Devonshire. (*Rymer's Fœdera*, vol. i. p. 195.) Fresh supplies of foreigners contributed to advance the woollen trade of these districts.

Kendal, in Westmoreland, claims the honour of first receiving John Kemp, where his descendants still remain, and the woollen trade is at present carried on. In the following reign, we find the manufacturers of Kendal petitioning to be relieved from the regulations imposed on broad-cloths. Kendal green is mentioned by Shakspeare as an article of dress in the time of Henry IV., and there is reason to believe, that in the reign of Elizabeth, the woollen manufactures of that town were as extensive as at present.

In the year 1336, two woollen manufacturers from Brabant settled at York, under the king's protection: they are styled in the letters of protection, "Willielmus de Brabant & Hanckcinus de Brabant, Textores." These persons probably laid the foundation of the woollen and worsted manufactures, which have since so extensively flourished in the western part of that county. It is not very improbable, that the manufacturer Hancks, called Hanckcinus,

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gave the name to the skein of worsted, which is to this day called a hank.

The references which we have soon afterwards to the woollen manufacture, as existing in the districts before-named, tend to confirm the belief, that the distribution of the foreign manufacturers we have given is correct. About this time, we learn that Thomas Blanket, and other inhabitants of Bristol, set up looms in their own houses, but were so harassed by the impositions of the mayor and bailiffs of the place, that they were obliged to obtain letters from the king to permit the free use of their trade, without impediment, calumny, or exaction. The letter to the mayor and bailiffs accuses them in the following terms: "vos diversas pecuniarum summas ab eisdem Thomas et aliis exigitis et ea occasione multipliciter inquietatis et gravatis, ut asserunt." Dr. Parry has conjectured, that blanket, which at first meant a coarse white undressed cloth, derived its name from the same Thomas Blanket of Bristol. The encouragement given to the woollen manufacturers during this reign, and the consequent consumption of wool at home, diminished the export of it so much, that a duty was laid on cloth exported to supply the place. Blackwell-hall was appointed by the mayor and common council of London for the market, where cloth manufacturers might send their goods for sale, in the year 1357.

In the course of the reign we find several other acts relating to the measurement and fulling of cloth, and the fees to be paid to the aulnager.

In order to form a more distinct idea of the relative value of wool, cloth, and other articles, after and before the reign, it may be proper to refer to the state of the silver coinage.

	Grains.
The 28 Edward I. one shilling contained	264
18 Edward III. - - - -	236
27 Edward III. - - - -	213
9 Henry V. - - - -	176
1 Henry VI. - - - -	142
4 Henry VI. - - - -	176
49 Henry VI. - - - -	142
1 Henry VIII. - - - -	118
34 Henry VIII. - - - -	100
36 Henry VIII. - - - -	60
37 Henry VIII. - - - -	40
3 Edward VI. - - - -	40
5 Edward VI. - - - -	20
6 Edward VI. - - - -	88
2 Elizabeth - - - -	89
43 Elizabeth - - - -	86

at which it continued to the present reign.

The following account of the exports and imports in the 28th of Edward III., said to be found in a record of the exchequer, was published by Edward Misseldon, merchant, in the year 1623.

Exports.	£	s.	d.
Thirty-one thousand six hundred and fifty-one sacks and a half of wool, at six pounds value each sack, amount to	189,909	0	0
Three thousand thirty-six hundred and sixty-five felts at 40s. value, each hundred at six score, amount to	6,073	1	8
Whereof the custom amounts to	81,624	1	1
Fourteen last, seventeen dicker, and five hides of leather, after six pounds value the last, amount to	89	5	0
Whereof the custom amounts to	6	17	6
Carried forward	277,702	5	3

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	£	s.	d.
Brought forward	277,702	5	3
Four thousand seven hundred and seventy-four cloths and a half, after 40s. value the cloth, is	9,549	0	0
Eight thousand and sixty-one pieces and a half of worsted, after 16s. 8d. value the piece, is	6,717	18	4
Whereof the custom amounts to	215	13	7
Summary of the out-carried commodities in value and custom	294,184	17	2

Imports.

One thousand eight hundred and thirty-two cloths, after six pounds value the cloth	10,922	0	0
Whereof the custom amounts to	91	12	0
Three hundred and ninety-seven quintals and three quarters of wax, after the value of 40s. the hundred or quintal	795	10	0
Whereof the custom is	19	17	0
One thousand eight hundred and twenty-nine tons and a half of wine, after 40s. per ton	3,659	0	0
Whereof the custom is	182	0	0
Linen cloth, mercury, and grocery-ware, and all other manner of merchandize	23,014	16	0
Whereof the custom is	285	18	3

Summary of the in-brought commodities, in value and custom, is	38,970	13	3
Summary of the impulse of the out-carried above the in-brought commodities, amounteth to	255,214	3	11

Admitting the correctness of this statement, which we have no reason to doubt, we must observe, that the cloth imported was of a higher value per yard than the cloth exported. Hence it may be inferred, that for several years after the arrival of the Flemish weavers, we were partly dependent on foreigners for our fine cloths; the coarser kinds then, as at the present day, forming the larger quantity of our exports. It is obvious also, that worsted goods had become an article of manufacture, nearly equal in importance with the woollen; and hence it is not improbable, that the greater part of the Flemish manufacturers were makers of stuffs and worsted goods, which was probably an entirely new trade in England.

The statutes in the following reigns, relating to the woollen manufacture, prove the narrow and selfish policy by which the manufacturers were influenced: these statutes refer either to restrictions which they wanted to impose, in order to confine the trade to themselves, or are made to prevent them from fraudulently packing or weaving their goods. In consequence of these fraudulent practices, the 13th statute of Richard II. makes the following regulations, which are curious, as marking the spirit of the manufacturers, and also as proving the early establishment of the woollen trade in the western counties, where it now flourishes. It runs thus: "Forasmuch as divers plain cloths, wrought in the counties of Somerset, Dorset, Bristol, and Gloucester, be tacked and folded together for sale; of which cloths a greater part be broken, bruised, and not agreeing in the colour, neither according to the breadth, nor in no manner to the part of the same cloths shewed outwards, but falsely wrought with divers wools, to the great loss and

damage of the people, inasmuch that the merchants that buy the same, and carry them out of the realm to sell to strangers, be many times in danger to be slain, and sometimes imprisoned and put to fine and ransom. Therefore it is ordained, that no plain cloth tacked and folded shall be set to sale within the same counties." The same act permits certain cloths of coarse wool to be made of the breadth of three quarters, and appoints one weight and measure through the kingdom, except in the county of Lancaster. Another statute, in the same reign, allows every person to make cloth of what length and breadth he will, provided the aulnage and other duties are paid, and it be measured and sealed by the king's aulnager, and contain no deceit. The kinds of worsted goods which might or might not be exported, were also specified in this statute. During this reign it appears, notwithstanding the increase of our trade, that we annually exported about one hundred and thirty thousand packs of wool, paying a duty of one hundred and sixty thousand pounds.

In the 4th of Henry IV. the cloths made in London and the suburbs were ordered to have a seal of lead attached, and in a subsequent statute no cloths were to be folded before the aulnager had set his seal to them. In the following reign, the narrow cloths, called the dozens of Devonshire and Cornwall, are ordered to pay cocket customs, after the rate of broad-cloths.

In the reign of Henry VI. the exportation of woollen yarn is prohibited, and this prohibition seems to have been in full force when wool was allowed to be freely exported. The only reason assigned for this is, that the yarn paid no duty. During this reign two cloth-searchers were appointed for every hundred throughout the realm, who were to inspect and seal all cloth, taking one penny for each. This proves that the manufacture of woollens had spread over a great part of the kingdom. It is probable that this inspection extended to all cloths made in private families, which were sent to the fulling-mills.

The worsted trade was also increasing rapidly at this time: four wardens of worsted-weavers were appointed for the city of Norwich and two for the county of Norfolk, who were to make due search of worsteds, and of what length and breadth they were made. In the same reign it was ordained, that "if our woollens were not received in Brabant, Holland, and Zealand, then the merchandize growing or wrought within the dominions of the duke of Burgoine shall be prohibited in England, under pain of forfeiture." Hence we learn, that we very soon began to supply these same countries with woollens and worsteds, from which we had received workmen a century before.

In the third year of Edward IV. the woollen trade had increased so much, that the importation of woollen cloth, caps, &c. was prohibited. Woollen caps or bonnets were then universally worn; they were either knitted or made of cloth, and a large quantity of wool must have been consumed in their fabrication. About the year 1482, hats made from felts were introduced; but the manufacturers of caps, called the cappers, continued a powerful body a century afterwards. In the same reign, the wardens of worsteds at Norwich were doubled, or increased to eight.

The manufacture of fine broad-cloth must have been considerably improved about this time; for in the fourth of Henry VII. it was thought prudent to fix a maximum on the price of fine cloth, by which every retailer of cloth who should sell a yard of the finest scarlet grained cloth above sixteen shillings, or a yard of any other coloured cloth above eleven shillings, was to forfeit forty shillings per yard for the same.

In the year 1493, in consequence of a quarrel between Henry VII. and the archduke Philip, all intercourse between the English and Flemish ceased, and the mart for English goods was transferred from Antwerp to Calais. This interruption to the regular course of trade was severely felt by the woollen manufacturers. Lord Bacon, mentioning the renewal of the trade with Flanders, which took place again in 1496, says, "By this time the interruption of trade between the English and Flemish began to pinch the merchants of both nations very sore. The king, who loved wealth, though very sensible of this, kept his dignity so far as first to be sought unto. Wherein the merchant adventurers likewise did hold out bravely; taking off the commodities of the kingdom, though they lay dead upon their hands for want of vent." The merchant adventurers he describes as "being a strong company, and underfet with rich men." It is not, however, very probable, that this company would continue to purchase goods without a prospect of gain. These merchant adventurers were divided into two bodies; those of London, which were the most powerful; and the merchant adventurers of England, who paid a fine to the former on all goods sold at the foreign marts.

In the reign of Henry VIII. the woollen trade, and particularly all kinds of worsted manufactures, appear to have been in a very flourishing state, though trade suffered several severe checks from the wars in which we were engaged. In the year 1527, Henry having entered into a league with France against the emperor Charles V., all trade with Spain and the Low Countries ceased. The goods sent to Blackwell-hall found no purchasers, the merchants having their warehouses filled with cloths; the poor manufacturers being thus deprived of employment, an insurrection took place in the county of Suffolk, where four thousand of them assembled, but were appeased by the duke of Norfolk. The merchants were summoned to appear before cardinal Wolsey, who in the name of the king reprimanded them in an angry tone for not purchasing the goods brought to market, and threatened them that his majesty would open a new mart at Whitehall, and buy of the clothiers to sell again to foreign merchants; to which menace one of them pertinently replied, "My lord, the king may buy them as well at Blackwell-hall, if it pleases him, and the strangers will gladder receive them there than at Westminster."—"You shall not order that matter," said the cardinal; "and I shall send into London to know what cloths you have on your hands, and by that done, the king and his council shall appoint who shall buy the cloths, I warrant you." With this answer the Londoners departed. Grafton's Chronicle, vol. ii. p. 1167-8.

The interference of the cardinal raised the spirits of the manufacturers for a time, but originating in ignorance of the nature of trade, it could only have a temporary effect, and goods fell again till a truce between England and Flanders was made for the benefit of trade. This fact shews the dependance of England, even at that time, on the export of manufactured woollens. In this reign we find Lancashire and Cheshire first named as seats of the manufacture of coarse woollens; they are mentioned, together with Cornwall and Wales, as districts where friezes were made. It appears from various references, that Norfolk and Suffolk were then flourishing seats of the worsted manufacture, and of all goods made with a worsted warp. Wardens were allowed to the towns of Yarmouth and Lynn, but with a selfish restriction, that the pieces were to be dyed, spun, or callendered in the city of Norwich. In the last year of this reign, an act was passed to prevent any

persons besides woollen manufacturers, who bought wool for their own use, and merchants of the staple, who bought for exportation, to purchase wool with the intent to sell again. This act extended to twenty-eight counties, and secured a monopoly of the wool to the merchants of the staple, and to the rich clothiers. In the first year of the following reign, Edward VI., it was repealed, so far as to allow every person dwelling in Norwich and Norfolk, to buy wool the growth of that county, by themselves or agents, and retail it out in open market. The reason assigned is this: That almost the whole number of poor inhabitants of the county of Norfolk and city of Norwich had been used to get their living by spinning of Norfolk wool, which they used to purchase by eight pennyworth or twelve pennyworth at a time, selling the same again in yarn; and because the grower chose not to parcel it in such small quantities, therefore for the benefit of the poor, the wool of Norfolk was allowed to be purchased by wool-dealers. By this act, the 33d of Henry VIII., for prohibiting the exportation of yarn is made perpetual. The manufacture of woollens in the counties adjoining London appear to have been extensive, particularly in the county of Berkshire; for in the beginning of the reign of Henry VIII., John Winchcombe, of that county, commonly called Jack of Newbury, was celebrated as the greatest clothier in England. He kept one hundred looms in his own house, and in the expedition against the Scotch, he sent to Floddenfield one hundred men, fully equipped, at his own expence. Even so early as the 13th century, one Thomas Cole was distinguished by the name of the rich clothier of Reading, in Berkshire.

York, then the second city in the kingdom, and from its connection with the port of Hull well situated for the export trade, was probably an early seat of the woollen manufacture. We have already mentioned the settlement of two clothiers from Brabant in the time of Edward III. We do not learn precisely in our early historians, when the manufactures emanated from that city into the western parts of the county; but from an act in the 34th of Henry VIII. we are informed, that the chief manufacture of that city was the making of coverlets; the act recites, "that the poor of that city were daily employed in spinning, carding, dyeing, weaving, &c. for the making of coverlets, and that the same have not been made elsewhere in the said county till of late; that this manufacture had spread itself into other parts of the county, and was thereby debased and discredited, and therefore it is enacted, that none shall make coverlets in Yorkshire but the people of York." Thus we see, under the flimsy pretext of public benefit, the manufacturers were willing to disguise that selfish spirit of monopoly, which disgraces almost every page of our commercial history. The municipal regulations of the city of York, which were, and still continue to be, hostile to a free trade, probably obliged many manufacturers, who were not sharers in the monopolies of the guild, to establish themselves in the western villages of the county, where provisions were cheaper, and where they could carry on their trade without restriction. In the reign of Philip and Mary, soon after this period, we have the following interesting account of Halifax, in consequence of an act passed in the 37th of Henry VIII. to prevent any other persons than merchants of the staple and woollen manufacturers from buying wool in the county of Kent and twenty-seven shires. The poorer manufacturers, who were unable to lay in their stock of wool at one time, being hereby deprived of their trade, made application for redress, which was granted. The act recites as follows: "Whereas the town of Halifax being

planted in the great waste and moors, where the fertility of the ground is not apt to bring forth any corn nor good grass, but in rare places, and by exceeding and great industry of the inhabitants; and the same inhabitants altogether do live by cloth-making, and the greater part of them neither getteth corn, nor is able to keep a horse to carry wools, nor yet to buy much wool at once, but hath ever used to repair to the town of Halifax, and there to buy some two or three stone, according to their ability, and to carry the same to their houses, three, four, or five miles off, upon their heads and backs, and so to make and convert the same either into yarn or cloth, and to sell the same, and so to buy more wool of the wool-driver; by means of which industry, the barren grounds in those parts be now much inhabited, and above five hundred households there newly increased within these forty years past, which now are like to be undone and driven to beggary by reason of the late statute (37th of Henry VIII.) that taketh away the wool-driver, so that they cannot now have their wool by such small portions as they were wont to have, and that also they are not able to keep any horses whereupon to ride or fetch their wools further from them in other places, unless some remedy may be provided. It was therefore enacted, that it should be lawful, to any person or persons inhabiting within the parish of Halifax, to buy any wool or wools at such time, as the clothiers may buy the same, otherwise than by engrossing and forestalling, so that the persons buying the same do carry the said wools to the town of Halifax, and there to sell the same to such poor folks of that and other parishes adjoining, as shall work the same in cloth of yarn, to their knowledge, and not to the rich and wealthy clothier, or any other to sell again. Offending against this act to forfeit double the value of the wool so sold."

From this we learn that many woollen manufacturers had been either driven from York at an early period, by the oppression of the municipal regulations, or had retired where provisions were cheaper, and where they had better streams for the erection of fulling-mills, and for other processes of the manufacture, such as dyeing and scouring.

The woollen manufactures also gradually retired from the vicinity of the metropolis, owing to the increased price of provisions and labour, and probably also to the difficulty of obtaining commodious streams for the scouring and fulling of cloth, when the country round London became more populous. In the latter part of the reign of Henry VIII. we are informed, that the king demised to William Webbe the subsidy and aulnage of all cloth made in the county of Monmouth, and in the twelve shires of Wales. A former act of this reign, speaking of the manufacturers of North Wales, says, they had been used to sell their cloths so craftily and hard rolled together, that the buyer could not perceive the untrue making thereof. These acts prove the extension of the woollen manufactures westward.

In the same reign, an act mentions the woollen manufactures as being established in Worcestershire, but prohibits any one from making cloth in the county, except within the city of Worcester, and in the towns of Evesham, Droitwich, Kidderminster, and Bromsgrove; and forbids the owners of houses in those places from letting them at advanced prices to the cloth-manufacturers. The woollen manufacture has continued to the present day at the two last of these towns. In the reign of Edward VI. Coventry and Manchester are mentioned as manufacturing places. The manufacturers in the old established seats of the woollen trade appear to have been greatly alarmed at the extension of the cloth manufacture, and to have exerted all their influence to restrain it. Near the conclusion of the reign of

Philip and Mary, an act in 53 sections was passed, relating to the making of woollen cloths. It enacts, that no person shall make woollen cloth but only in a market-town, where cloth hath commonly been used to be made for the space of ten years last past, or in a city, borough, or town corporate. From this restricting act, however, the following exceptions are made: to all persons who dwell in North Wales or South Wales, Cheshire, Lancashire, Westmoreland, Cumberland, Northumberland, the bishopric of Durham, Cornwall, Suffolk, Kent, the town of Godalmin in Surrey, or in Yorkshire, being not within twelve miles of the city of York, or any towns or villages near the river Stroud in Gloucestershire. This act, so absurd and oppressive, was obliged to be modified in the first year of the following reign, by an act entitled "An Act for the continuing and making of Woollen Cloths in divers Towns in the County of Essex." Bocking, Wetherfold, Cockhill, and Dodham, are the towns specified.

In consequence of the increase of our manufactures, the export of wool had nearly ceased before the reign of Elizabeth; and a considerable advance appears to have taken place in the price of food, clothing, and rents. The export trade of England was carried on very extensively by three companies of merchants, the merchants of the Stillyard, who were foreigners, the merchants of the Staple, and the merchant adventurers, who were English. See STILLYARD, STAPLE, and ADVENTURERS.

The merchants of the Stillyard were of ancient standing, and were originally from the Hanse towns: they had great privileges granted them, and particularly they were allowed to export and import all wares and merchandize, on payment of the small duty of one and a quarter *per cent.* This gave them a decided advantage over the other companies; and it is alleged that they lent their name to cover the import and export of goods belonging to private merchants, and thereby evaded the regular duties on such goods. This company had engrossed a considerable part of the cloth trade. In the year 1551 they exported 44,000 cloths; soon after which this company was dissolved. The merchant adventurers succeeded to that branch of their trade: according to the account of John Wheeler, secretary to the company, there were annually shipped by them 60,000 white cloths, worth 600,000*l.*, and 40,000 cloths of all sorts, baizes and kerseys, worth 400,000*l.*, besides wool and woollens. We are told by Camden, that, in this reign, the commerce between England and the Netherlands rose to above twelve millions yearly, and the woollen trade alone amounted to five millions. The Latin terms which Camden employs, *milliones aureorum*, leaves the amount intended uncertain: if we suppose it to be ducats, the quantity is much greater than England exported at that time; probably florins were intended, which makes the amount about 750,000*l.*

Besides the exports to Antwerp, English cloth was at this time sent to Amsterdam, Hamburg, Sweden, Russia, and other countries. The woollen trade of England had now advanced to a higher state of prosperity than at any former period; and from this time it appears to have declined until after the revolution of 1668. In this reign, the price of wool, which we believe to mean long or combing wool, had advanced from 1*3s.* 4*d.* to 22*s.* *per* tod; and the shilling containing the same weight of silver as our late coinage, *viz.* 86 grains, the relative value of a tod of long wool was considerably more than it has ever been during the present reign.

The declension of our manufactures in the succeeding reigns of the Stuarts, as we have reason to believe, extended much more to woollen cloths than to worked pieces. Long

wool, or combing-wool, was more the peculiar produce of England than clothing-wools. The latter were grown in abundance, and of a superior quality, in Spain, Portugal, and France; but the combing-wools of England, on account of the superior soundness of the staple or fibre, and the quantity supplied, gave a decided advantage to our manufacturers of stuffs or worked pieces.

The persecution of the Protestants by the duke of Alva in the Netherlands drove multitudes of the manufacturers into England, where they were graciously received by Elizabeth, who gave them liberty to settle at Norwich, Colchester, Sandwich, Maidstone, and Southampton. These refugees contributed to extend our manufactures of worked goods and light woollens, called bays and fays; they also introduced the manufacture of linens and silks, and it is supposed that they first taught the art of weaving on the stocking-frame.

In the latter part of the reign of Elizabeth an act was passed to relieve the counties of Somerset, Gloucester, and Wiltshire, from those absurd and oppressive statutes which confined the making of cloth to corporate towns. This act, which gave to all persons residing in these counties the privileges of free trade, could not fail to extend and establish the woollen manufactures in these parts, and they have remained to the present time the principal seats of the superfine cloth trade, whilst many manufacturing corporate towns, which were then flourishing, have sunk to decay. Various acts, regulating the length, breadth, and tentering of woollen goods of different kinds, were also passed in this reign, referring to the counties of Oxfordshire, Devon, and the counties north of Trent, particularly Yorkshire and Lancashire. The importation of foreign wool-cards was also prohibited. The act recites, that many thousands of woollen card-makers and card-wire drawers, living in London, Bristol, Gloucester, Norwich, Coventry, and elsewhere, had heretofore subsisted themselves and families upon that business, which was now greatly impaired by the importation of wool-cards. No laws prohibiting the export of wool were thought necessary in this period of our history, and it continued to be exported during the whole of this reign, as appears by the account of the merchant adventurers, who exported it together with cloth; but though wool was freely exported, an act was passed to prevent the carrying of live sheep, lambs, or rams out of England; but the reasons for this act are not recited, though it states it was for divers good causes and considerations. The internal tranquillity that the country enjoyed during this long reign, the influx of foreign makers of new kinds of worsteds, and other articles not known before, the opening of a new trade to Turkey and the Barbary states, by treaty in the year 1579 and in 1585, all greatly contributed to the extension of the woollen trade and manufactures. There were indeed other circumstances which must have operated against our manufacturers in part of this reign. The interruption of commerce between England and the Netherlands in 1564, which lasted some time, the wars with Spain, the sacking of Antwerp, in which the English merchants suffered severely, gave a considerable check to the foreign trade; yet we have seen that the merchant adventurers alone exported woollens to the amount of one million sterling towards the latter end of this reign. The demand at home for woollens must also have greatly increased during the long period of domestic tranquillity which the nation at that time enjoyed, and particularly from the prevailing taste for costly dresses which has spread from the court through the country.

A great part of our woollen exports hitherto consisted of white undressed cloth; but in the following reign of James I. it was represented as bad policy to permit the exportation of cloth in this state, and thereby lose the profit on the

dyeing and finishing. A letter exists addressed to king James on this subject, ascribed to sir Walter Raleigh, but without sufficient evidence, as "the most ancient manuscripts of this letter in the libraries of the nobility ascribe it to John Keymer." (Oldy's Life of Sir W. Raleigh.) In this letter it is stated, "that there have been eighty thousand undressed and undyed cloths exported yearly, by which the kingdom has been deprived of four hundred thousand pounds for the last fifty-five years, which is nearly twenty millions that would have been gained by the labour of the workmen in that time, with the merchants' gains for bringing in dyeing-wares, and return of cloths dressed and dyed, with other benefits to the realm." The writer proceeds, in another part, to state, that there had also been exported in that time annually, of baizes and northern and Devonshire kerseys, in the white, fifty thousand cloths, counting three kerseys to a cloth, whereby had been lost about five millions to the nation in labour, profit, &c. The author informs us, that the baizes so exported were dressed and dyed at Amsterdam, and shipped to Spain, Portugal, and other kingdoms, under the name of Flemish baize, setting their own seal upon them; "so that we lose the very name of our home-bred commodities, and other countries get the reputation and profit thereof." The author concludes with asserting, that the nation loses a million a year by the export of white cloths, which might be dressed and dyed as well at home. This letter has been often quoted as containing unanswerable reasons for confining the whole process of the cloth manufacture to our own country; but, like other monopolists, the writer seems to forget that there are two parties in all mercantile transactions, and that manufactured goods must be sent in that state in which the purchaser is willing to receive them, unless it be proved that he cannot procure them elsewhere. Let us mark the result. Alderman Cockayne, and other London merchants, had sufficient influence with the government to obtain the prohibition of the export of white cloths, and to secure a patent for dressing and dyeing of cloths. In consequence of which, the Dutch and Germans immediately prohibited the importation of dyed cloths from England, which gave so great a check to our export trade, that in the year 1616, the whole amount of cloths exported of every kind amounted only to sixty thousand, so that the export trade in woollens had fallen to less than one-third of its former amount; and in the year 1622,

	<i>l.</i>	<i>s.</i>	<i>d.</i>
All our exports of every kind } amounted only to }	2,320,436	12	10
Whilst our imports were	2,619,315	0	0
Leaving a balance against us of	298,878	7	2

It being from experience proved, that the policy of dressing and dyeing all our goods at home had produced the greatest injury to the woollen trade, the restrictions were taken off, and the export for white cloth left free. In the former reign, cloths about four pounds value were, by statute, to be sent out dyed, by all persons except the company of merchant adventurers, who obtained a licence to export all sorts of white cloths; and though this was itself a monopoly, yet, as it gave foreigners an opportunity of receiving our finer cloths in the state which they most wanted, it was the means of increasing our trade: indeed it is said by Misselden, that "within a few years after granting this licence, the vent for cloth in foreign parts increased to twice as much as it had been during the strict observance of the statute." With this fact before their eyes, it is scarcely possible that our statesmen at that time could have proceeded to the pro-

hibition of white cloth exports, unless they had been (as was asserted) influenced by presents from alderman Cockayne and the rich merchants, who expected to receive the benefit arising from the prohibition, and the exclusive right of dyeing and dressing. The wool-growers equally felt the ill effects of this prohibition. Wool is said to have fallen from thirty-three shillings *per* tod to twenty shillings; if by this is meant the long combing-wools, the former price, considering the value of money at that time, is much higher than it has been in the last or the present century.

During the reigns of the Stuarts, the infamous policy they adopted struck not only at the liberty, but at the commercial prosperity of the country. Archbishop Laud, imbued with the malignant zeal of a bigot, commenced his attacks on the descendants of the French Protestants, established as manufacturers of woollens in Norfolk and Suffolk, from which counties his persecuting fury drove some thousand families. Many of them settled in New England; but others went into Holland, where they were encouraged by the Dutch, who allowed them an exemption from taxes and rents for seven years. In return for this, the states were amply repaid by the introduction of manufacturers, with which they were before unacquainted. In the year 1622, king James issued a proclamation to prohibit the exportation of wool, fuller's-earth, &c. In 1640 wool was again admitted to be exported on the payment of certain duties; and we are told, that in the same year sir John Brownlowe, of Belton in Lincolnshire, sold three years' wool at twenty-four shillings *per* tod to a baize-maker of Colchester. As it is reasonable to suppose that this was the long combing-wool of that county, it shews the high relative price of the article at that time. In 1647, owing to the high price of wool, its exportation was again prohibited.

During the civil wars, the manufactures and export trade of England declined, and the Dutch availed themselves of this to extend their own manufacture and export of woollens, particularly to Spain, from whence they brought fine Spanish wool. At this time it appears, that the woollen manufactures in Poland and Silesia were rapidly increasing; and the English government received information that two hundred and twenty thousand cloths were made there annually, besides considerable quantities made at Dantzic, and in the vicinity.

The duke of Brandenburg, it was also stated to our government, had ordered one hundred thousand ells of Silesia cloth at Königsberg for his troops, which had been heretofore supplied with English cloth. The estimation in which our cloth had been held is said to have been lost by negligence in the manufacture, particularly in the spinning and weaving. The Dutch and Poles had a little before this time received a great number of Protestant manufacturers, who fled from the persecution of the duke of Alva in Brabant and Flanders.

Here it may be proper to remark, that the English as a nation had little intercourse with other parts of the world, except through a few large trading companies: hence they were extremely ignorant respecting the state of foreign countries, and supposed that the cloth trade had been confined to their own country for three hundred years; and they considered the establishment of other manufacturers as a novelty and infringement of their just rights. With these views, it was proposed to obtain a complete monopoly of all the clothing-wools in Spain, in order to prevent the Dutch and other nations from rivalling our manufactures. This is the more extraordinary, as the English had not then learned, like the Dutch, to manufacture Spanish wool, without mixing it with that of their own country. It is needless to say, that

the negociation of sir William Godolphin for this selfish monopoly of wool was not successful. During the whole reign of Elizabeth, when our woollen manufactures were in the highest state of prosperity, wool and woollens were permitted to be exported. In the reign of James I. and Charles I., when the trade was declining, proclamations were issued to prevent the exportation of wool, and also that of fuller's-earth. During the commonwealth, an ordinance of parliament was issued to prohibit the exportation of wool and fuller's-earth, on pain of forfeiture of the wool, and a penalty of 3*s.* per pound on every pound of fuller's-earth. The first act of parliament which absolutely prohibited the exportation of wool by making it felony, and which could not be set aside by a royal licence, is the 12th of Charles II., which was passed soon after the Restoration.

The grounds of this measure are stated in the preamble of the act: "For the better preventing the losses and inconveniences which have happened by and through the secret and subtle exportation of wool out of the kingdom; and for the better setting to work the poor people and inhabitants of the kingdom, to the intent that the full and best use and benefit of the principal native commodities of the kingdom may redound to and be unto and amongst the subjects and inhabitants of the kingdom, and not unto any foreign states." Previous to this time, the proclamations and ordinances issued to prevent the exportation of wool, for the most part, signified nothing more than the imposition of a duty or a composition for exporting by licence from the government, what on other terms was forbidden, under penalties of confiscation, fine, or imprisonment. We have seen that, from the death of Elizabeth to the Revolution in 1688, the woollen trade was generally in a languishing state. In the year 1665, Thomas Telham of Warwickshire, with two thousand manufacturers, left the kingdom, and established themselves in the Palatinate, and commenced a woollen manufacture there, and were greatly encouraged by the elector. The establishment was soon afterwards joined by a number of manufacturers from Hertfordshire.

During the period from Elizabeth to the year 1668, the English appear to have made no improvement whatever in their modes of manufacture of woollen cloth, whilst the neighbouring nations had been making a gradual progression, both in the style of their manufacture, and the amount annually produced. It was especially in the manufacture of fine cloths that their superiority was manifest. The Dutch, in particular, were far more expert than the English in the dressing and dyeing of cloth. This will appear from the following remarkable fact stated by Coke, vol. ii. p. 169. In the year 1668, one Brewer, with about fifty Walloons, who wrought and dyed fine woollen cloths, came into England, and received the royal protection and encouragement. By him the English were first instructed how to manufacture cloth of the best Spanish wool, without any admixture with inferior wool; and also to manufacture and dye fine cloths cheaper by 40 *per cent.* than they had done before. Ten years before this time, it had been published and admitted in England, that "Spanish wool alone could not be wrought into cloth." It may seem truly extraordinary that the English, who had so long carried on the manufacture of woollen cloth, had not availed themselves of the revolution in Flanders, which drove away the best master manufacturers, to encourage their settlement in this country. M. Huet explains the fact in a way which is not very creditable to the liberality of the English manufacturers, or to the wisdom of our institutions. "It was owing to the municipal laws of England, and its usages towards strangers; who, besides being doubly rated at the custom-house, were excluded from all companies or fraternities of trade; and were

not allowed to carry on manufactures as matters or partners, unless such as the natives were unacquainted with; so that none of the Flemish master manufacturers of fine cloth went thither (to England), their's being a mystery not accounted new, though very much superior to the cloth working then known in England. It was only those who wrought in new kinds of worsteds, serges, damasks, or stockings, who went thither. The same policy was also adopted by the Hanse towns: hence the greater part of the vast and profitable trade, which was lost to Antwerp, centered necessarily in Holland, where the manufacturers from Brabant were cordially received." This appears a satisfactory explanation why the English, in 1668, were so much inferior to the Dutch in the manufacture of fine cloth.

In the year 1660, however, our manufacturers began to be aware of the superiority of Spanish wool, and to mix it with the best English, probably in what were called medleys or mixture-cloths, or else employing the English wool for warp, and covering it with worst of Spanish wool. The best Spanish wool was then 4*s.* and the second sort 3*s.* per pound, and the best English 1*s.* 6*d.* per pound.

It is deserving of notice, that, in the latter period of the Commonwealth, our trade is said to have greatly revived, but to have suffered a miserable depression almost immediately after the restoration of Charles II. In a letter of M. Downing of the Hague to the president of the council in London, 1660, printed in Thurloe's State Papers, vol. vii. p. 848. it is stated, that great quantities of wool were brought secretly from England to Holland; and he adds, that the Dutch had at that time got in a great measure the manufacture of fine cloth, and would probably, with Silesia, engross also the manufacture of coarse cloth, and leave England nothing but its native wool to export.

In the year 1662, great complaints were made against the merchant adventurers for their neglect of the cloth trade; in reply to which they said, that the demand for English cloths failed in the foreign markets, the white clothing trade having abated from 100,000 cloths annually to 11,000. In the year 1663 our whole exports were only about two millions, and our imports four, leaving a balance of two millions against this country. It is, however, deserving notice, that the number of wardens for the inspection of stuffs at Norwich being too few, they were at this time increased from five to eight. A letter on the state of trade, published in 1667, says, clothing-wools were so much fallen at that time, that the best Spanish was sold at 2*s.* 2*d.* per pound, and English at 8*d.* per pound. The writer ascribes the fall in the price of English wool to our wearing so much Spanish cloth, a great part not manufactured by ourselves, as Dutch blacks; but it is obvious, from the price of Spanish wool, that the low price of clothing-wools at that time depended on a more general cause, affecting all manufacturing countries. To relieve the cloth trade from the great depression under which it laboured between the years 1660 and 1678, various schemes were devised. Among others, the mayor and common council of London passed an act "for the regulation of Blackwell-hall, Leaden-hall, and Welsh-hall, (the three public markets for cloth in London,) and for preventing foreigners buying and selling!" By foreigners are understood all persons not free of the city of London. This act, a most singular monument of the ignorance or selfishness of its authors, prohibits the sale of all woollen cloths sent to London, except at the above halls, where certain duties were to be paid upon them, and from whence they could not be removed for three weeks, unless they were sold in the meantime to some draper, or other freeman of the city. The hall-keepers were to attend strictly at the halls, and

turn out all foreigners and aliens coming to purchase cloth; and every freeman of the city who should introduce a purchaser into the halls not free of the city should forfeit, for the first offence, five pounds,—for the second, ten,—and for the third, fifteen pounds! Thus, in those days, turning purchasers out of the public markets, and securing the sale to a certain class of buyers, was considered an act for the benefit of the public.

The Irish had, a little before this time, commenced the manufacture of woollens and worsteds, which appears greatly to have alarmed the English manufacturers. The wools of Ireland had increased in quantity, in consequence of a tyrannical act passed a little before this period, to prevent the Irish from sending cattle to England, which obliged them to convert their grounds into sheep-pastures. They were, however, prohibited from exporting their wool to foreigners, it being made felony; and the exportation to England, in any other than a raw state, exposed it to confiscation. About the year 1640 some clothiers from the west of England established a woollen manufacture at Dublin, where it flourished a considerable time. About the same period, sixty families of manufacturers from Holland settled at Limerick: these were ruined by the wars which ensued. Other English clothiers settled at Cork and Kinsale; a few French manufacturers of druggets settled at Waterford; and a more considerable establishment of the cloth manufacture was formed at Clonmel, supported by the capital of some London merchants, who had agents there. These establishments, though obviously inadequate to the supply of one-fourth part of the population of Ireland, excited great jealousy in the English manufacturers; and during the great depression of the woollen trade between the years 1660 and 1668, a part of this distress was ascribed to the rivalry of the Irish clothiers. The English farmers, at the same time, ascribed the low price of wools to the great importations of wools from Ireland; and the merchants ascribed the failure of the foreign demand for cloth to the clandestine exportation of English and Irish wools.

Sir William Petty, in the year 1672, estimates the sheep in Ireland at four millions, and the weight of each fleece at two pounds. The latter, however, is obviously not more than half the true average weight of the fleece, and the number is supposed by some to be below what it was a few years afterwards. If the number of sheep be correct, and taking the fleece of each at four pounds, this would make the total amount of Irish wools only 66,000 packs, of which three-fourths were consumed in Ireland.

The alarm and jealousy excited in England by the Irish woollen manufactures produced measures that almost compelled the Irish to export their wools clandestinely to the continent. An act was passed in the year 1699 prohibiting the exportation of woollen manufactures from Ireland, except to a few parts in England and Wales, where the duties imposed amounted to a total prohibition. Various addresses have been presented to the king and both houses of parliament, "beseeching his majesty to take effectual measures to prevent the growth of the woollen manufactures in Ireland." The Irish parliament was influenced to impose a duty in the same year of four shillings in the pound on their own manufactures when exported. These unjust proceedings were intended to annihilate the export trade for Irish woollens; and, in consequence, their wool and worsted yarn that was not consumed at home were sent to England, or to the continent clandestinely. The first four years after the destruction of their manufactures, these exports to England were as follow:

	Stone of Wool, 18lbs. per Stone.	Stone of Yarn, 18lbs.	Total of Wool and Yarn.
1700	336,292	26,617	362,909
1701	300,812	23,390	326,202
1702	315,473	43,648	359,121
1703	360,862	36,873	397,735

The average annual amount of wool and yarn, as above, may be stated at thirty thousand packs. But after this period the exports to England declined, owing no doubt to the clandestine exportation of wool to the continent, for which the numerous creeks and harbours offered such facility.

In 1711, and the three following years, the quantity exported to England was as under:

	Wool.	Yarn.	Total.
1711	310,136	52,273	365,409
1712	263,946	60,108	324,054
1713	171,871	68,548	240,409
1714	147,153	58,147	205,800

A few years after this, the decline was still more considerable in the amount of wool exported, but that of yarn continued to increase a little:

	Wool.	Yarn.	Total.
1726	51,371	87,261	138,632
1727	58,182	72,047	130,229
1728	49,784	80,428	130,212
1729	38,667	91,854	130,521

A further encouragement to clandestine importation was given by an impolitic duty of 2s. 4d. per stone on wool sent to England, which, as the average price did not exceed 6s. 6d., was full thirty per cent. on the first cost. It will be seen subsequently, that the woollen manufactures of England were all this time progressively increasing, so that the decline in the imports of wool from Ireland were not occasioned by a declension of trade; the Irish had found other markets for their wool.

From a work entitled "A New Discourse of Trade," by sir Joshua Child, supposed to have been published about the year 1667, we learn several important particulars respecting the woollen trade. "Though our vent for fine cloths and stuffs to Turkey, Italy, Spain, and Portugal, were, he says, declined, yet we retained a considerable part, principally because the wool of which our middling coarse cloths are made is our own, and consequently cheaper to us than the Dutch can steal it from us." In another part he judiciously observes, that the acts for regulating manufactures, resolve themselves at last into a tax on the commodity, without respect to the goodness of it, as most notoriously appears in the business of aulnager, which doubtless our predecessors intended for a scrutiny into the goodness of the cloth; and to that purpose a seal was invented as a signal, that the commodity was made according to the statute; which seal, it is said, may now be bought by thousands, and put upon what the buyers please. Sir Joshua Child admits that wool was eminently the foundation of English riches, and that all possible means should be used to keep it within the realm; but the only efficacious measures to effect it are not penal statutes, but encouragement to trade. The impediments at that time he states to be, 1st, The high rate of interest; 2d, Want of hands, which an act of naturalization would cure; 3d, Compulsion (persecution) in matters of religion. For he adds, "while our neighbours the Dutch have money at lower interest and more hands, by reason of general liberty of conscience, with other free privileges, both to natives and foreigners, there is no question but they will be able to give a better price for our wool than we can afford ourselves, and they that can give the best price for a commodity shall never fail to have it by one means or another, notwithstanding the

opposition of any laws by sea or land; of such, force, subtilty, and violence, is the general course of trade."

The same enlightened writer appears to have been the first Englishman who saw the injustice, absurdity, and impolicy of the numerous restrictions by which the manufacturers were obliged to make cloths of certain weights and lengths, to keep only a certain quantity of looms, or to prohibit dyers, fullers, &c. from carrying on other branches of the trade. "It would be (he justly observed) for the advantage of the trade of England, to leave all men at liberty to make what cloth and stuffs they please, how they will, when and where they will, and of any lengths or sizes."

One of the principal causes of the decay of our woollen manufactures Sir Joshua Child might not think it prudent to state. This was the encouragement given to the consumption of French cloths and woollens in England, together with the total prohibition of English goods imported into France, or the imposition of duties which amounted to a prohibition. The French, under the administration of Colbert, had been extending and improving every branch of the woollen manufacture, and were become our great rivals in foreign markets, as well as at home. In the year 1678, acts were passed, the 29th and 30th of Charles II., prohibiting the importation of French commodities for three years. From this time trade began gradually to revive, and would have greatly increased, had not political causes operated as a check to our prosperity.

The improvements introduced in the manufacture of fine cloths by Brewer in 1668, and the more extensive consumption of Spanish wool, enabled us to oppose, with some success, the rivalry of the French.

After the accession of William, our manufacturers, who were warmly attached to the cause of religious liberty, being the greater part Protestant dissenters, were animated to uncommon exertions in the restoration of their trade. This is evident from the state of our exports in the following year after the revolution in 1689, when they amounted to near seven millions, of which the woollens were nearly three millions. This is the largest amount till the year 1715. A short time after the revolution, about the close of the century, our writers on Political Arithmetic, Mr. King and Dr. Davenant, give the following estimate of our national wealth, including wool, &c.:

		£
The annual income of England, of which the		
people subsist	- - - - -	43,000,000
Yearly rent of land	- - - - -	10,000,000
Value of wool yearly shorn	- - - - -	2,000,000
Woollen manufacture of England	- - - - -	8,000,000
Woollen manufactures exported	- - - - -	2,000,000

From this period, the woollen trade of England kept progressively increasing, though subject to some fluctuations. In the following years the amount exported were as under:

	£
1718 value of woollens exported	2,673,696
1719 - - - - -	2,730,297
1720 - - - - -	3,059,049
1721 - - - - -	2,903,310
1722 - - - - -	3,384,842

About the year 1722, the plague at Marseilles, by preventing the exportation of French woollens, increased the demand for English manufactures considerably. In the year 1737, the woollen exports amounted to 4,158,643*l.*; and it is remarkable, that at that period the price of wool was uncommonly low.

The yearly medium value of woollen exports,	£
from 1739 to 1748, or to the peace of Aix-la-Chapelle, was	3,327,057
Yearly medium of woollen exports, from 1749 to 1753, was	4,189,195

From this time to the period of the American war in 1775, the woollen manufactures, and particularly the worsted, still continued to increase, with occasional checks. The quantity of long combing-wools grown in England had given to the manufacturers of worsted goods a decided advantage over those of France, though the ingenuity of the latter in the manufacture of les petites draperies, as the worsted goods are called, was greatly superior to what our own workmen had ever shewn. The demand for worsted goods at home, for tammies and stuffs, which were the general dress of females before the year 1775, was very great; besides which, we supplied with worsted goods many of the southern parts of Europe, and particularly Spain and Portugal, for the use of their South American colonies, and for the dresses of the clergy, monks, and nuns, which form no inconsiderable part of the population in those countries. About the year 1775, the introduction of Arkwright's inventions for spinning, carding, &c. into the cotton trade, produced a great change in the article of female dress in England, stuffs and tammies being supplanted by cotton goods, which were become extremely cheap. The failure of the foreign trade also greatly affected our manufacturers, both woollens and worsteds. The price of English wool at the latter end of the American war was lower than it had been in any period of our history, when money was of much higher relative value. A tod of 28lbs. of the best Lincolnshire wool for combing was not worth more than nine shillings, and the inferior kinds six shillings, or about three-pence and four-pence *per* pound. From the time of Elizabeth to the middle of the last century, scarcely any alteration or improvements had taken place in the processes of manufacture, either in woollen or worsted, beyond the variation of colours or patterns, to suit the fashion of the day. The ingenious mechanical inventions of Arkwright, applied to the spinning and carding of cotton, were soon after modified, and applied to the woollen and worsted trade, and produced an entire revolution in some of the seats of their manufacture. Before that period, the manufacture of heavy woollens and coarse worsted goods had been gradually concentrating into Yorkshire and Lancashire, where the cheapness of living, the active industry of the inhabitants, and, above all, the cheapness and abundance of coal, gave the manufacturers a decided advantage over those in the midland and western counties. The following table, shewing the amount of broad and narrow cloths made in the West Riding of Yorkshire, will prove the fact most decisively. It may be proper to remark, that eighty years since, about 1738, when our woollen exports exceeded four millions sterling, the total number of pieces of broad and narrow cloth made in Yorkshire was only fifty-six thousand nine hundred. At present our woollen exports are only about double what they then were; but the number of cloths manufactured in Yorkshire is not less than four hundred and ninety thousand pieces, or eight times more than the quantity made at the period above referred to. It must be remarked also, that this account does not include the cloth manufactured in Lancashire, and the borders of Cheshire adjoining Yorkshire, nor the blankets, serges, baizes, flannels, cassimeres, tolinets, carpets, rugs, worsted goods, or any other description of woollens or worsteds, except plain and narrow broad-cloths. The total amount of these different woollen articles exceed, we believe, in weight, if not in value, that of the woollen cloths.

An Account of the Number of Broad Cloths, milled at the several Fulling Mills in the West Riding of the County of York, from the 24th of June, 1725, (the Commencement of the Act,) to the 12th of March, 1726, and thence annually, distinguishing each Year; and of the Narrow Cloths, from the 1st of August, 1737, (the Commencement of the Act) to the 20th of January, 1738, and thence annually, distinguishing each Year; likewise the Number of Yards in Length, made each Year, from Easter Sessions, 1768.

Years.	Broads.		Narrows.		Years.	Broads.		Narrows.	
	Pieces.	Yards.	Pieces.	Yards.		Pieces.	Yards.	Pieces.	Yards.
1726	26671				1772	112370	3223913 $\frac{3}{4}$	95539	2377517 $\frac{1}{2}$
1727	28990				1773	120245	3635612 $\frac{1}{2}$	89874 $\frac{1}{2}$	2306235
1728	25223 $\frac{1}{2}$				1774	87201	2587364 $\frac{3}{4}$	88323	2133583
1729	29643				1775	95878	2841213	96794	2441007
1730	31579 $\frac{1}{2}$				1776	99733	2975389	99586	2488140 $\frac{1}{2}$
1731	35563				1777	107750	3153891	95786	2601583
1732	35548 $\frac{1}{2}$				1778	132506	3795990	101629	2746712
1733	34620				1779	110942	3427150	93143	2659659
1734	31123				1780	94625	2802671	87309	2571324
1735	31744 $\frac{1}{2}$				1781	102018	3099127	98721	2671397
1736	38899				1782	112470	4458405	96743	2598751
1737	42256				1783	131092	4563376	108641	3292002
1738	42404		14495		1784	138023	4094335	115500	3356648
1739	43086 $\frac{1}{2}$		58848		1785	157275	4844855	116036	3409278
1740	41441		58620		1786	158792	4934975	123025	3536889
1741	46364		61196		1787	155748	4850832	128740	4058157
1742	44954		62804		1788	139406	4244322	132143	4208303
1743	45178 $\frac{1}{2}$		63545		1789	154134	4716460	145495	4409573
1744	54627 $\frac{1}{2}$		63065		1790	172588	5151677	140407	4582122
1745	50453		63423		1791	187569	5815079	154373	4797594
1746	56637		68775		1792	214851	6760728	190468	5531698
1747	62480		68374		1793	190332	6054946	150666	4783722
1748	60765		68080		1794	190988	6067208	130403	4634258
1749	60705 $\frac{1}{2}$		68889		1795	250993	7759907	155087	5172511
1750	60447 $\frac{1}{2}$		78115		1796	246770	7830536	151594	5245704
1751	60964		74022		1797	229292	7235038	156709	5503648
1752	60724		72442		1798	224159	7134114	148566	5180313
1753	55358		71618		1799	272755	8806688	180168	6377277
1754	56070 $\frac{1}{2}$		72394		1800	285851	9263966	169262	6014420
1755	57125		76295		1801	264082	8699242	137231	4833534
1756	33590 $\frac{1}{2}$		79318		1802	265660	8686046	137016	5023754
1757	55777 $\frac{1}{2}$		77097		1803	266785	8942798	139575	5023996
1758	60396		66396		1804	298178	9987255	150010	5440179
1759	51877 $\frac{1}{2}$		65513		1805	300237	10079256	165847	6193317
1760	49362 $\frac{1}{2}$		69573		1806	290269	9561178	175334	6430101
1761	48944		75468		1807	262024	8422143	161816	5931253
1762	48621		72946		1808	279859	9050970	144624	5309007
1763	48038 $\frac{1}{2}$		72096		1809	311239	9826048	151911	5951762
1764	54916		79458		1810	273664	8671042	158252	6180811
1765	54660		77419		1811	269892	8535559	141809	5715534
1766	72575 $\frac{1}{2}$		78893		1812	316431	9949419	136863	5117209
1767	102428		78819		1813	369890	11702837	142863	5615755
1768	90036		74480		1814	338869	10656491	147474	6045472
1769	92522	2771667 $\frac{1}{2}$	87762	2144019	1815	330310	10394466	162355	6649859
1770	93075	2717105	85376	2255625	1816	325449	10135285	120901	5650669
1771	92782	2966224 $\frac{1}{2}$	89920	2235625	1817	351122	10974473	132607	5233616

In the table that will be afterwards given, it will be seen that the quantity of yards of different woollen articles exported, which are not included with cloths, greatly exceeds that of broad and narrow cloths. Taking this as a standard, it would appear that the cloth returned at the fulling-mills in the West Riding of Yorkshire is not more than one-third of the total quantity of woollens and worsteds of every description made in the West Riding of Yorkshire, and the borders of Cheshire and Lancashire. Now to make the quantity of broad and narrow cloth given in the returns of the West Riding, would require about one hundred and ten thousand packs; we may therefore state the annual consumption of wool in these districts to be from two hundred and fifty to three hundred thousand packs of 240 pounds each; and we may further state the amount consumed in these districts to exceed that of all the other parts of England and Wales collectively by one-third, including hosiery and all other articles made of wool. This will make the total amount of wool manufactured in England to be nearly what we have before estimated, or five hundred thousand packs.

The number of persons immediately employed in the various branches of the woollen manufacture in England was stated, in the year 1800, to be 1,500,000, and that the trade directly and collaterally employed double the above number. This was asserted in the speech of Mr. Law, now lord Ellenborough, in the house of lords, as council for the petitioners against the export of wool to Ireland. But we apprehend that the statement greatly exceeds the actual number employed in this trade, including their families.

The amount of the population of the West Riding of Yorkshire is nearly ascertained, and perhaps two-thirds of the whole may be engaged in the woollen manufacture, including the families of the persons employed. If we state these to be 340,000, exclusive of the woollen manufacturers in Cheshire and Lancashire, we shall certainly not under-rate them. A large part of the West Riding being agricultural solely, and in the manufacturing districts cutlery, as at Sheffield, and cottons in the more western parts, employ no inconsiderable portion of the people. If then we take 340,000 as the amount of persons, with their families, engaged in the woollen trade in the West Riding, exclusive of Lancashire and Cheshire, and if we suppose that they are one-third of the total number of persons employed in the same manufacture in England, it will make the whole rather exceed 1,000,000 of manufacturers, including their families, which we apprehend is not far from the true estimate. We shall, however, give the precise words of Mr. Law's speech in the house of lords on the above occasion, the object of which, it must be recollected, was to enhance the importance of the woollen manufacture. "In order to give your lordships some idea of its magnitude, I may venture to state, that there are no less than 1,500,000 persons who are immediately concerned in the operative branches of this vast manufacture; and if what Dr. Campbell states in his 'Political Survey of the Kingdom' be true, that from the wool-grower to the consumer a piece of broad-cloth passes through 100 different hands, and that there are nearly the same number of hands dependent on the woollen manufacture, though not actually concerned in it, I may assume that the trade directly and collaterally employs double the above number of hands, or 3,000,000. If we estimate the magnitude of this question (the export of wool) according

to the number of persons interested in it, it goes to nearly one-third of the entire population of this kingdom, estimating that population at what is generally reckoned, namely between 9 and 10,000,000." Though the woollen manufactures of England have considerably increased within the last fifty years, we do not apprehend the number of hands employed is greater than before the introduction of mechanical inventions for carding, spinning, and combing. The working up of one pack of wool, particularly of combing-wool, formerly employed a great number of hands, and was divided into small portions, to be spun in the houses of cottagers in remote districts. This afforded employment to the wives and families of labourers who were engaged in agriculture; but so much time was occupied in taking out and collecting in the work, that at the period we refer to, few, if any, of the master manufacturers in Yorkshire consumed more than one pack of wool *per week* in their trade. At present there are numerous manufacturers in Yorkshire and Lancashire, who consume from twenty to fifty packs of wool *per week*.

The cotton manufacture, which may be regarded as of recent date, has employed the population that would otherwise have been thrown out of work in the woollen trade since the introduction of machinery, and has prevented any inconvenience of this kind from being felt at present in Yorkshire. We may, however, observe, that many branches of the woollen and worsted trade have been gradually retiring from the south of England, and concentrating in the West Riding of Yorkshire and in Lancashire. These districts were the first to introduce mechanical improvements into the woollen manufacture, and thus gained a decided advantage over the more ancient seats of the woollen trade. For several years afterwards the effects were felt in the manufacturing districts in the west of England, and great distresses from want of due employment for the labouring classes was the consequence.

At present all kinds of machinery that have hitherto been applied to wool are extensively employed in the west of England, and the manufacture of superfine cloth is in a flourishing state in the counties of Gloucestershire, Somersetshire, and Wiltshire, all ancient seats of the clothing trade. The manufacture of broad-cloth in other parts of the south and west of England is not carried on to any great extent. The manufacture of flannels, serges, baizes, &c. though branches of the woollen manufacture, are distinct from the cloth trade, and seldom carried on in the same district.

The export of woollen goods of all kinds from England, in the year 1815, amounted in declared value to ten millions one hundred and ninety-eight thousand pounds. This was rather an extraordinary quantity; and in the following year the exports fell under nine millions, which may be taken as the regular annual amount of woollen exports at present.

The following table gives the amount of different kinds of woollens exported, with their value, and the places to which they were sent in the year 1816; a year in which our foreign trade was considered as in a declining state. It may be worthy of remark, that though our woollen exports scarcely reached eight millions and a half, the amount taken by the United States of America in that year exceeded three millions; a fact which proves the vast importance of the American market to our manufacturers.

An Account of the Quantity of Woollen Goods exported from Great Britain, in the year ending the 5th possible, the various Articles,

Countries to which exported.	Quantity and declared Value of Woollen									
	Cloths of superfine, second, and inferior Quality.		Napped Coatings, Duffles, &c.		Cassimeres.		Baizes of all Sorts.		Flannel.	
	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.
	Pieces.	L.	Pieces.	L.	Pieces.	L.	Pieces.	L.	Yards.	L.
Russia - - - - -	79671	777074	27	153	2180	19857	128	565	62436½	5633
Sweden - - - - -	56½	979	—	—	1	4	—	—	832	54
Norway - - - - -	588	4921	217	949	60	378	27½	165	4335	389
Denmark - - - - -	717	7447	34	130	354	2308	—	—	8142½	646
Poland - - - - -	2	45	—	—	—	—	—	—	100	10
Prussia - - - - -	83	1100	67	324	214	1544	3	18	1324	137
Germany - - - - -	9274	54042	27740	110457	27882	103534	200	580	144972	9494
Holland - - - - -	9892	53294	13374	63462	2374	9367	1741	11950	37928	3373
Flanders - - - - -	3164	23086	6586	29540	1575	7364	13	94	44555	4602
France - - - - -	73	721	—	—	67	910	¼	3	1944	154
Portugal, &c. - - - - -	39854	292141	7466	38755	3931	30037	13114	80377	14859	1355
Spain, &c. - - - - -	3395½	30286	1228	5071	930	5975	5584	38139	42554	4411
Gibraltar - - - - -	4344	32520	1270	6805	950	5415	883	4886	79720	8913
Italy - - - - -	7729	45360	2772	11765	658	3395	48	285	20623	1535
Malta - - - - -	8453	45964	1305	5466	811	4274	53	198	4730	537
Turkey and Levant - - - - -	185	2850	51	258	—	—	—	—	1450	160
Ireland and Isle of Man - - - - -	21734	327049	61	399	4008	60851	91	556	200707	18898
Isles, Guernsey, Jersey, & Alderney - - - - -	991	13975	93	515	20½	194	140½	540	25054	2213
Asia - - - - -	19433	407614	170	936	231	2777	330	1374	225487	28130
Africa - - - - -	1485½	17396	498	2538	1122	6586	241	1460	14386½	1209
America; viz. United States - - - - -	195124	1463028	19798	73143	39899	263284	4446	12787	2288758	187940
—— British Northern Colonies - - - - -	32412	246504	1827	5544	2248½	15442	1051	4227	484129	35971
—— West Indies - - - - -	16649½	114544	529½	1926	2708	16991	8109	40098	69729	6451
—— Foreign Continental Colon. - - - - -	33319	238796	5409	30863	2911	18888	13926	80236	12999	895
—— Honduras - - - - -	30	337	—	—	50	312	—	—	700	53
Total - - - - -	488658½	4201073	90522½	388999	95184½	579687	50129½	278538	3792454½	323163

of January, 1817, distinguishing the Countries to which exported, and also distinguishing, as far as and their respective Value.

Goods and Yarn exported from Great Britain.

Blankets and Blanketing.		Carpets and Carpeting.		Stuffs, Woollen or Worsted.		Stockings, Worsted.		Sundry Articles consisting of Hosiery not described, Rugs, Cover-lids, Tapes, &c.	Woollens, mixed with Cotton.		Woollen and Worsted Yarn.		Total declared Value of the preceding.
Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	
Yards.	L.	Yards.	L.	Pieces.	L.	Doz. Pts.	L.	L.	Yards.	L.	Lbs.	L.	L.
6742	885	30863	6335	2261	4723	208 0	276	1234	12433	2188	—	—	818923
58	7	1240	421	15	25	4 9	9	21	—	—	—	—	1520
268	37	645	155	479	1096	41 4	62	319	1715½	426	—	—	8897
382	51	1047	297	891	1850	10 0	13	152	786	270	—	—	13164
180	20	1130	265	52	120	—	—	—	—	—	—	—	460
—	—	1832	485	188	382	3 0	3	1028	2260	652	—	—	5673
12660	1285	73579	17742	37748	80244	3936 9	5201	15052	135862	26041	—	—	423672
7690	600	28737½	5462	31447	62391	8636 10	10384	3986	19730½	3968	—	—	228237
6663	685	6162	754	5635	13326	5145 6	6499	3645	31785	9072	—	—	98667
15	4	352	88	345	1112	196 0	240	443	2338	686	—	—	4361
44745	5026	18043	3394	27472	72091	3417 0	4153	35206	25190	5919	—	—	568454
10152	1189	6064	1086	11644	29281	2840 0	3666	25931	5846	1505	—	—	146540
2150	219	2600	474	10659	24874	892 10	1029	13846	19593	4563	—	—	103544
570	68	2765	627	14852	37930	62 0	84	1060	2894	720	—	—	102829
100	15	317	83	3682	9603	87 0	113	693	3382	389	—	—	67335
650	70	13595	3366	1816	4222	20 0	42	104	—	—	—	—	11072
30500	4727	46894	12042	8150	20883	12453 0	14156	11582	121483	25444	523638	65613	562200
4280	638	7211	1555	837½	2319	650 6	916	280	548½	150	—	—	23295
23824	3956	9879	2312	187820	572325	629 0	1039	8863	4044	895	—	—	1030221
14190	1237	3718	645	1638¼	3353	1520 0	1477	1139	2940	813	—	—	37853
1265746	165729	526964	109529	202061	609628	69059 6	75513	47802	198268	21284	—	—	3029667
258359	32455	69563	14293	21362	55511	18709 4	22190	8995	24103	4410	8757	2086	447626
233597	22153	3080	768	13094	27649	837 6	1133	4916	215912	14973	—	—	251602
39320	3750	9946	2008	9810	21845	2483 0	2851	7746	54805	9928	—	—	417806
1860	120	—	—	14	28	7 0	11	—	—	—	—	—	861
1964701	244926	866226½	184186	593972¾	1656811	131849 10	151060	194043	885918½	134296	532395	67699	8404481

If we state the amount of woollen goods exported to be about one-third of our own consumption, or from one-third to one-fourth, which is probably more correct, this would make the total value of manufactured woollens to exceed thirty millions annually. Of the woollen goods exported, the quantity consumed on the European continent scarcely exceeds three millions sterling in value, and a great part of that amount given in the preceding account was for army cloth. Hence it appears, that a very small proportion of the general population of Europe is indebted to this country for its woollens, including under the term both woollen and worsted goods. The increased demand for woollens of every description in England arises partly from the increase of population, but more from the increasing demand for articles of luxury or convenience. In the middle of the last century, carpets were scarcely to be seen in the country, except in the houses of the nobility; at present almost every house in England, except those of cottagers and the labouring classes, has carpets spread in some of the rooms. The consumption of worsted yarn in articles of furniture, and in the linings of carriages, and what is called horse millinery, is very great; add to which the people of England are better dressed than they were formerly. We may from all these causes state, that the home consumption of woollens, in proportion to our population, is double that of any other nation in Europe. To prove that we do not over-rate the proportion of woollens consumed at home, it may be sufficient to state, that the West Riding of Yorkshire alone manufactured, in the year 1817, nearly twice as many pieces of cloth as were exported in that year; but few woollen broad-cloths are made for exportation in the west of England, the manufactures there being principally fine and superfine cloth for home consumption, the value of which *per yard* on the average is much greater than that of the Yorkshire cloth. In the present state of Europe, we think it an encouraging circumstance to our woollen manufacturers, that so large a proportion of their goods are consumed at home, where the demand will remain certain; and again, that the United States of America take so considerable a part of our exports, as from the increasing population of these states, we may expect that the demand will be increasing for many centuries, and will soon exceed what it will be in the power of this country to supply.

In the year 1800, the woollen manufacturers of England were greatly alarmed at the liberty which was intended to be granted, of exporting wool to Ireland, and petitioned parliament against the measure. The grounds on which their alarms rested, were partly the preference given to the Irish, and partly the supposed facility that would be afforded to smuggling wool to the continent. Several manufacturers and wool-dealers from different parts of the kingdom were examined before the two houses of parliament; but neither in their evidence, nor in the speeches of the learned council, who were heard in support of the petitioners, can we trace any comprehensive or enlightened views of the subject. The objections urged against the export of wool were grounded principally on the practice of former reigns, particularly those of Edward III. and queen Elizabeth: but the facts we conceive were in opposition to the statements; for during the whole of the latter reign, in which our woollen manufactures were in a highly flourishing condition, the export of wool was freely admitted, on the payment of certain duties; and during the reign of Edward III., the prohibition to export wool under heavy penalties was confined to denizens and foreigners, in order to secure a larger amount of duties to the king, the former paying less duty on exports than natives; nor was it till the reign of Charles II. that the ex-

port of wool was strictly prohibited. All the former prohibitions were evadable by licences, which were readily granted for money. It is from this reign, therefore, we must date the prohibition to export wool, as forming an established law of the land; and it is not unworthy of remark, that immediately after this period, and to the time of the revolution in 1688, our woollen manufactures were in a very declining state, which proves that they had not derived much benefit from the measure. The policy of admitting the export of wool has been again recently agitated in parliament, and has renewed the alarm of the manufacturers. It is not by precedents drawn from former ages, but solely by the wisdom and justice of the measure, as applicable to one present condition, that a question of this kind should be determined. With respect to short or clothing wool, we believe that a permission to export it would not produce the least effect, as we already import these wools from almost every nation in Europe; it is not, therefore, probable, that foreigners would give a better price for them than our own manufacturers can afford. With long combing-wools, the case is somewhat different, as by the acknowledgment of the French themselves, these wools are wanted to mix with and improve their own. We apprehend, however, that as much is exported at present clandestinely in the form of worsted yarn, as the market may require, the free export of cotton yarn giving great facility for evading the penalty, by packing them together. The permission to export wool to Ireland, which was granted in 1800, has not been attended with any one of the fatal effects which our manufacturers anticipated; nor do we apprehend, that permitting the free export of wool under certain duties would be found to injure our own woollen trade.

In taking this view of the subject, which we trust is an impartial one, we readily admit that the permission to export wool, were it granted, would not be attended with any permanent benefit to the landed interest. A small pamphlet on the subject, recently published by John Maitland, esq., contains the following judicious observations:—"The manufacturer of our native wool claims from government the preservation of it for his use; for *by the statute law of the land, he is confined to its soil for the express purpose of working up the wool which grows upon it*. This wool cannot, therefore, upon any just or moral principle, be permitted to go out of the country in an unmanufactured state, without allowing the manufacturer to follow it, or without obliging the grower and exporter of it to maintain him and his children." This is so obviously just, that whenever the export of wool is admitted, we cannot any longer, as at present, prohibit the woollen manufacturers from emigrating and carrying their industry to the best market. "The wool," as Mr. Maitland elsewhere observes, "does not on an average compose more than one-sixth part of the value of the animal on which it grows; and the manufacturer, by obtaining this sixth part, at such a moderate rate as may enable him to sell his goods, when manufactured at a reasonable profit, insures to the owner of land a moral certainty of obtaining the full value for the remaining five-sixths, and receiving an ample price also for all the other productions of his ground." The truth of this observation we know to be fully proved in the Yorkshire markets. Whenever there is any considerable depression of the woollen trade, it is always attended with a decreased consumption of animal food, supplied principally from Lincolnshire, and the counties which produce the largest quantity of wool. Should the permission to export wool be attended with any effect in diminishing our own manufactures, the result would be highly injurious to the land-owner, who would then have to find new customers for

his general produce, and new associates to share with him the burden of taxation.

The prices of heavy combing-wool in Lincolnshire, Nottinghamshire, or Leicestershire, may be taken as the average price of this kind of wool over the whole kingdom, there being little variation in the value of this wool from different districts. The following table will shew what have been the prices for a great part of the last century :

Price *per* Tod of Lincolnshire Fleeces, the Tod weighing 28 lbs.

	£	s.	d.
1706	-	0	17 6
1707	-	0	16 6
1711	-	0	13 0
1713	-	0	17 0
1714	-	0	18 0
1715	-	0	18 0
1716	-	0	19 0
1717	-	1	3 0
1718	-	1	2 3
1719	-	1	2 0
1720	-	1	0 0
1721	-	1	0 0
1722	-	1	0 0
1723	-	0	17 6
1724	-	0	16 0
1725	-	0	16 0
1726	-	0	15 9
1727	-	0	16 0
1728	-	0	18 0
1729	-	0	18 0
1730	-	0	18 0
1731	-	0	19 0
1732	-	0	19 0
1733	-	0	18 6
1734	-	0	16 0
1735	-	0	14 0
1736	-	0	14 0
1737	-	0	14 0
1738	-	0	13 6
1739	-	0	13 0
1740	-	0	14 0
1741	-	0	14 0
1742	-	0	15 0
1743	-	0	19 6
1744	-	1	1 0

From the year 1744 to the year 1777, the prices, though occasionally fluctuating, continued much the same as in the preceding years, but we have not the means of ascertaining precisely what they were in each year. The following table will shew the prices of Nottinghamshire and Leicestershire heavy combing-wool, taken from the most authentic source. We consider the value of this wool to have been fully equal to that of Lincolnshire on each year.

Price *per* Tod of 28 lbs. of Nottinghamshire and Leicestershire heavy Combing-Wools.

	£	s.	d.
1777	-	0	18 0
1778	-	0	15 0
1779	-	0	11 0
1780	-	0	11 6
1781	-	0	10 6
1782	-	0	9 0
1783	-	0	12 0

	£	s.	d.
1784	-	0	16 0
1785	-	0	12 0
1786	-	0	13 0
1787	-	0	17 6
1788	-	0	17 0
1789	-	0	18 0
1790	-	0	18 0
1791	-	0	19 6
1792	-	1	2 6
1793	-	0	18 0
1794	-	0	17 6
1795	-	0	19 0
1796	-	1	1 0
1797	-	1	0 6
1798	-	0	18 0
1799	-	1	1 6
1800	-	1	4 6
1801	-	1	10 0
1802	-	1	10 0
1803	-	1	9 0
1804	-	1	12 0
1805	-	1	13 6
1806	-	1	12 0
1807	-	1	4 6
1808	-	1	4 6
1809	-	1	8 0
1810	-	1	10 0
1811	-	1	5 0
1812	-	1	10 0
1813	-	1	14 0
By the end of the year			
1814	-	2	2 0 to 2 12 0
Spring of 1815			
1815	-	2	16 0
1816	-	2	10 0
1817	-	1	10 0
1817	-	1	14 0 to 2 0 0

The above were the average prices of the best lots ; the inferior ones might range from one to two shillings *per* tod under the prices here given. It may be observed, that the price of this kind of wool was lower towards the close of the American war, or about the year 1781 and 1782, than in any former or subsequent period of our history, if we take into consideration the relative value of money. At that time, the quantity of wool unfolded in the hands of the farmer was nearly equal to three years annual growth ; a quantity too large to have been consumed by our manufacturers, had not the introduction of machinery enabled them to work it up with much greater facility than formerly. The average weight of these fleeces may be stated at four or seven pounds each fleece to the tod of 28 pounds. Since the commencement of the present century, the price of this kind of wool, it will be seen from the above table, has been amply sufficient to remunerate the wool-growers ; and we confess we are utterly at a loss to discover on what grounds of sound policy or interest they would wish to make any change in the laws respecting the export of wool. With respect to short or clothing wools, any change in the existing laws would make no alteration whatever in the price ; for it is the extreme of prejudice to assert, that our native clothing fleeces are necessary to the foreign manufacturer, either to supply his demand or improve the quality of his own wool. We might with equal justice revive the absurd opinion, so confidently maintained a few years since, that the best Spanish wool would not make cloth without an admixture with that of England.

WOOLLEN Manufacture, Process of. In an early part of this work, under the article CLOTH, we have given a general view of the process of cloth-making, furnished by a principal manufacturer in the west of England. In the present article, we shall confine our account chiefly to those improvements in the processes which have since been introduced, and shall add a description of the machines which were only slightly noticed in the article CLOTH, and give references to the plates. The processes of the woollen manufacture may be classed under two heads; those by which wool is prepared for the weaver, and those by which the cloth is finished after it is taken out of the loom. The sorting of wool has already been referred to under the article WOOL. English wool is supposed to be sufficiently cleaned from pitch marks or other extraneous substances by the wool-sorter, and left by him in a proper state to commence the process of cloth-making. Spanish wool in the bale has generally some part of the pitch employed to mark the sheep still adhering to it, which must be carefully cut off. It was till recently the practice to beat the wool with rods, in order to shake out the dust and open the staples; but this is now principally done by an opening machine with long coarse teeth, called a devil, or wool-mill. Spanish wool is frequently so hardly pressed together in the bag, that it requires to be opened out by beating, to prepare it for the further processes.

In the west of England, wool is generally scoured before it is dyed or carded; but in Yorkshire this is seldom practised on wool intended for white cloths, and among the smaller manufacturers who dye their own wool, it is frequently put into the dyeing-vat unscoured; a practice which injures the brightness of the colours, but which enables the manufacturer to make a greater weight of cloth with the same quantity of wool. There is also some saving of labour and expence; but this is more than counter-balanced by the increased quantity of oil *per* pack required for unscoured wool, which is at least one-third more than would be necessary if the wool were scoured. In the west of England, where the wool is scoured previously to its manufacture, the process is carried on with a degree of neatness and cleanliness, which form a perfect contrast with the horrid stench and disgusting filthiness of the woollen factories in Yorkshire. For fine cloths, olive-oil, called Gallipoli, from the part where it was supposed to be sent, is principally used; and for the coarser cloths rape-oil. Where attention to colour is not required in very coarse goods, fish-oil is sometimes employed; but if the latter remain in the wool or cloth, it turns it brown, undergoing a degree of fermentation injurious to the cloth, and which sometimes occasions spontaneous combustion. To lessen the expence of oil for coarse cloths, some manufacturers in Yorkshire make use of a mixture of soap and water with oil, which answers very well in moist weather, if the wool be immediately carded and spun; but if it remain some time unwashed, or the weather be very hot, the mixture evaporates. It has been attempted to work wool without any oil whatever, but without success. The use of oil is to cover the surface of the fibres, and enable them to slide easily over each other in carding or spinning. What we have before said of the structure of the surface of wool or hair, under the article WOOL, will suffice to shew the advantage that must result from oiling. The wool is sprinkled with oil as evenly as possible. In Yorkshire the proportion on fine wool is about six gallons *per* pack, and this is more equally distributed over it by the wool-mill, through which it passes previous to the process called scribbling. This process is a kind of coarse

carding, and is performed on a machine similar to that used for scribbling cotton, but larger, and with coarser cards, the principle being similar to that of the carding-machine, hereafter to be described. By this engine the longer fibres are broken down, and they are all laid straight and nearly parallel to each other. The wool leaves the roller of the scribbling-mill in one thin undivided sheet, and the more clear, even, and transparent it appears when held between the eye and the light, the more perfectly has the operation been performed. On the carding-engine, the operation is repeated on finer cards; but instead of leaving the machine in one continued sheet, it is finally divided into separate portions, which by a fluted roller are formed into separate round pieces about one inch in diameter, and two feet three inches in length. The fibres are now arranged so as more easily to slide over and twist round each other in the next process, which is a kind of coarse spinning called *slubbing*, performed with the *slubbing-machine*, which will be described. On this machine each of the rolls from the carding-machine are joined together, and drawn out into a loosely-twisted thread, and wound round a spindle, forming what is technically called a *slubbing*. These *slubbings* being taken to the spinning jenny, which will also be described, are twisted in an opposite direction, and drawn out into threads of yarn of the requisite length. For very fine yarn used in shawls, a machine called the mule is sometimes employed, nearly similar to the cotton mule (see *Manufacture of Cotton*), the *slubbing* passing through rollers which assist in drawing out the thread smaller and more regular. The yarn is now prepared for winding, sizing, warping, and weaving. (See CLOTH.) Since the article CLOTH was written, broad-cloth is almost universally woven by one person only in a loom, making use of the fly-shuttle. (See WEAVING.) The next process is scouring and burling, already described under the articles CLOTH and FULLING. The cloth is then sent to the fulling-mill; the finer kinds are prepared for fulling by a mixture of soap and water; in coarse kinds, fuller's-earth supplies the place of soap. (See FULLING-Mill, and a farther description at the end of the article.) The principle on which the felting depends has been described under the article WOOL. By the process of fulling, the cloth becomes shortened in length and breadth, and the fibres are incorporated and intimately united with each other. In the best manufactured cloths, this incorporation is so complete, that the separate threads can scarcely be distinguished, the bottom of the cloth appearing to form one even continuous substance. An improvement in this respect has recently been made at Leeds, by spinning the wool much softer and thicker than has usually been the practice, and uniting the threads in the fulling-mill, and then working the substance of the cloth down to a requisite degree of thinness by the gig-mill, hereafter to be described. At the end of the process, the face or surface of the cloth is much softer, and greatly superior in appearance to cloth manufactured in the common process. A pack of wool of 240 lbs. will make when milled about one hundred and twenty yards of mixed or coloured cloth from fifty to sixty inches in breadth, according to the quality and fineness of the wool. The process of raising, shearing, and pressing, have been mentioned under the article CLOTH, and will be more fully described when an account is given of the gig-mill and shearing-machine. The object of these processes is to cover the thread with a soft pile, consisting of the fibres of the wool, cut down to an even surface over the whole piece.

There are various kinds of woollen goods worked on the same principle as cloth, and made with both the warp and the

weft of carded wool, but which being unmilled, or finished in a different manner, receive different names. Blankets are manufactured on the card, but from wool that possesses a greater length of staple, and which therefore admits of a deeper pile, being raised on the surface. The yarn is spun thicker, and left as soft as possible, in order that it may form a full cover or pile. Fine blankets are made much flouter and heavier than coarse ones; they are both scoured in the mill, but are scarcely suffered to undergo the fulling process. Thick cloths with a long pile, called duffields, fearnoughts, and bear-skins, are manufactured on the same principle as blankets, but they are milled much thicker and dyed, and also raised to a deeper pile. Flannels and very light cloths, such as Bath coatings, are usually spun small, in proportion to the quality of the wool. In weaving plain cloths, the chain or warp is equally divided by the gears, one half of the threads being above and the other half below, and they cross each other every time the thread of the weft is thrown through by the shuttle. In weaving kerseymeres or cassimeres, on the contrary, the warp is unequally divided, to produce what is called the twill, or twelc, (see *WEAVING*,) one-third being always above and two-thirds below the shuttle as it passes. It is owing to this arrangement of the warp, that it forms a slanting or diagonal rib across the body of the cloth, which is the distinguishing character of this kind of woollens. See *DRAUGHT of Looms*.

Cassimeres are usually set in the loom from thirty-four to thirty-six inches wide, and milled to twenty-seven inches. Forty pounds of wool from the bag will make rather more than sixty yards of common milled fine cassimeres; the double milled ones make less in proportion to the degree of milling they receive.

Swandowns and toilinetts are made with a cotton warp; the weft is woollen or worsted yarn of various colours, according to the patterns required. Woollen cords have also the warp of cotton and the weft of woollen; they are woven and cut precisely in the same manner as cotton cords. See *FUSTIAN*.

Serges are made with the warp of worsted and the weft of coarse woollen yarn, and are twilled. These goods have been for a very long time manufactured extensively in Devonshire, and are principally purchased by the East India company for the China trade.

Carpets have worsted warps and woollen wefts. See *CARPET* and *WEAVING*.

From the most remote period of the woollen manufacture until the latter end of the last century, or about the year 1780, very few, if any, mechanical improvements had been introduced into it. During the whole time the various processes were carried on nearly in the same manner, but with greater or less skill, and were employed upon materials more or less valuable. The carding and spinning of wool, and the weaving and finishing of cloth, in the early part of the reign of George III., were effected by the same machines as in the time of Edward III., which probably were similar to those of the ancient Romans, but more rude in their construction. In an art which had seen so many centuries roll on without any change, it did not appear possible to the manufacturer that any improvement could be effected; and had not the genius of Hargreaves and Arkwright changed entirely the modes of carding and spinning cotton, the woollen manufacture would probably have remained at this day what it was in the earliest ages of civilized society. That it would have been better for general society if it had so remained we readily admit; but after the improved modes of working cotton were discovered, this was impossible. The spinning jenny, which was the same as that employed in

the cotton manufacture, but somewhat larger, was introduced into Yorkshire from Lancashire about the year 1780, but did not become general till about three years afterwards. In the first jennies, not more than eighteen or twenty threads could be spun, and the mode of winding the thread upon the spindle was very imperfect. The carding was still effected by the hand, and the slubbing or roving was prepared on the common spinning-wheel. For some time considerable difficulty was experienced in carding by machinery, particularly in clearing the wool from the card; and a slight change in the construction of the machine was found necessary to prepare the wool for the slubbing-billy, of which an account will be given in the description of the carding-machine. Soon after this, the carding and spinning of wool and yarn by machinery became general through the manufacturing districts of the West Riding of Yorkshire, and large mills were erected, in which the carding and scribbling machines were turned by a water-wheel, and the roving or slubbing performed on the billy. The wool carded at these mills was sent to the smaller manufacturers in the state of slubbing, and the farther process of spinning was effected on jennies in their own premises. Before the year 1787, the old processes of carding by the hand, and spinning on the wheel, were entirely discontinued in Yorkshire; but it was some years after before the new processes were generally introduced in the west of England, and thus, as we have before stated, the woollen trade became more concentrated in Yorkshire, where cloths could be manufactured at less expence. About this time, machinery began to be applied to the combing and spinning of long combing-wool, to make worsted yarn. See *WORSTED Spinning*.

In consequence of the great increase of trade in Yorkshire, it was found difficult to obtain situations for mills to be turned by water, and the application of the steam-engine to woollen machinery became very general. The abundance of fuel was highly advantageous to the Yorkshire manufacturer; and it was found to be equally cheap to work the machines by steam as by water, where any considerable rent was paid for the water. The motion of the improved steam-engine was also rendered as regular as a water-wheel, and the great inconvenience and loss from the interruption of the works by frosts or continued droughts were thereby avoided.

The smaller manufacturers in Yorkshire were at first benefited by the introduction of machinery, but in a little time large capitalists began to engage in the woollen trade, and performing all the processes with their own machinery, they were enabled to work cheaper and undersell the smaller makers. The facility also with which wool could now be worked up kept the markets always well stocked with goods, and prevented the manufacturers from taking the advantage of a temporary scarcity or a brisk demand, which they had formerly done, an overstocked market always reducing the profits.

Soon after the year 1800, the number of small manufacturers began rapidly to decrease many of them, being ruined by the change which had taken place, and compelled to become workmen in the factories of the large capitalists.

The gig-mill and the shearing-machine were not introduced into Yorkshire until they had been several years employed in the west of England, owing to the resistance made to them by the working cloth-dressers or croppers in the north.

The manufacture of worsted is properly a branch of the woollen manufacture, and noticed as such in our history of its progress in England; yet the mode of manufacture, both in preparing the worsted yarn and finishing the goods, being

entirely different from woollens made of carded wool, and part of it being applied to hosiery, we refer, for a further account of it, to the articles *WORSTED Manufacture*, and *WORSTED Spinning*.

Description of the Machines employed in the Woollen Manufacture.—The *wool-mill*, or *willy*, is the first machine which is employed on the raw wool to open and disentangle the close matting, in which the wool comes from the wool-stapler. It is also used for clearing the dyed wool from the dye stuff, and again for mixing different parcels of wool together; also for incorporating the oil with the wool.

The wool-mill used in Yorkshire consists of a cylindrical drum, about three feet long and two feet and a half diameter, which is made to revolve near three hundred times *per minute*. Its circumference is furnished with teeth or spikes, and immediately above it five small rollers are placed, which are also furnished with similar teeth. The teeth of the rollers and those of the drum intersect each other when they all turn round; and the teeth of the five small rollers also intersect each other. The cylinder and rollers are inclosed in a box or case, which is closed on all sides, except a door in front, which turns down, the hinges being at the lower side. When this door is shut up it stands in a perpendicular plane, very near to the teeth of the drum; when the door is opened, or turned down into the horizontal position, the wool is laid upon it, about one pound weight at once, and the door being closed the wool is brought within reach of the teeth of the cylinder, which take the wool and carry it upwards, so as to work it between the teeth of the cylinder and those of the five rollers placed over it. This effects the opening of the wool, and breaks the fibres if the staple is too long: it also separates the matted fibres. In about three seconds, the pound of wool is generally sufficiently worked, during which time the cylinder has made about fifteen turns. The lower part of the case in which the cylinder revolves is a grating of wooden rods, through which the dirt and dust escape. The cylinder is fitted very close to this grating, so that the wool cannot escape from the cylinder, but is carried round in it, and is thus repeatedly submitted to the action between the teeth of the cylinder and those of the rollers. When it is judged that the wool is sufficiently worked, the door is opened again, and the centrifugal force throws out the wool in an instant; a fresh charge is then laid upon the door, and shut up in the machine. A preferable mode is to have two doors on opposite sides of the case; one to put in the raw wool, and the other for the finished wool to come out at.

The wool for coarse goods is passed several times through the wool-mill; first, to break the mats of the raw wool and render it light; then a second time after it is dyed; a third time to mix the different sorts together; and lastly, after the wool is oiled, it is passed a fourth time through the wool-mill, with a view to incorporate the oil well with the fibres of the wool.

Scribbling-Machine.—This is the first stage of carding. The operation tends to disentangle the fibres which were before closely entangled, and draw them out separately, so as to render the wool light and flaky. The scribbling-machine is very similar to the carding-machine, having a large cylinder or drum, which is covered on the surface with sheets of leather stuck full of projecting wire-teeth, called card-wires. The teeth are so close together as to cover the whole surface of the cylinder, like the bristles of a brush. This cylinder is turned rapidly round by the machinery, and the wool is regularly and slowly supplied by feeding machinery to its teeth, which take it up, and the cylinder, as it were, clothes itself with wool. This wool is carded or worked by

the teeth of several other smaller cylinders, called *workers* and *clearers*, which are fixed around the great cylinder in pairs. The teeth of the workers take the wool from the great cylinder, and give it to the clearers, which return it again to the great cylinder. It is then transferred to another worker, and by its clearer is given back to the great cylinder, and so on. It is by the repeated transferring of the wool from one cylinder to another, that the chief action of scribbling or carding is performed. The teeth of the different cylinders do not actually touch each other, but they work so near together, that the fibres of the wool which the teeth of one card contains are caught by the teeth of the other card, and drawn out a very few at a time. This action tends to separate the fibres, and renders the wool light and open, and also distributes the wool with great evenness over the surfaces of the cylinders. After the wool has passed between three or four pairs of workers and clearers, it is taken up by a cylinder, called the *doffer*, which is smaller than the great cylinder, and turns round very slowly. The wool is stripped off from this doffer by a steel comb, which is situated parallel to the axis of the doffer, and is moved rapidly up and down by a crank through a small space. In ascending, the comb does not touch the doffer; but when the comb makes its down stroke, it comes in contact with the teeth of the cards, and combs out almost all the wool they contain. As the doffer turns round very slowly, and the comb acts at small intervals, the successive portions of wool which it combs or strips off, hang together in a continued fleece or web of a very thin texture, which hangs down from the doffer, and is received in a basket.

The wool in this state is said to be scribbled, but the fibres are not yet sufficiently combed out or separated; for on examination of the scribbled wool, many small knots and films of wool are found, which are still closely entangled. The scribbling is therefore repeated twice or three times, and then the wool undergoes another operation, which is called carding, but which is very nearly the same as the scribbling, only the wool is formed into small cylindrical rolls, which are the first rudiments of a thread.

We have thought it needless to give a drawing of a scribbling-machine, as it may be readily conceived from the following description of the carding machine.

Carding-Machine. (See Plate IV. *Woollen Manufacture*.)—A is the wood frame of the machine, but the best machines have cast-iron frames; C C is the outside of the large cylinder, which is about thirty inches diameter, and twenty-six inches wide: its axis is supported on bearings at each side of the frame, and it is put in motion by an endless strap applied upon a pulley at one end of its axis, which pulley cannot be seen in the figure. The cylinder revolves about 100 times *per minute*. B is an arch of wood to receive screws, which support the six small cylinders marked 2 a and 2; these are the workers and clearers. The workers 2 a are larger, and turn slower than the clearers 2; each worker is acted upon by its clearer, and both worker and clearer act against the cards of the great cylinder.

The raw wool is spread evenly upon the feeding-cloth 5, at one end of the machine: it is an endless sheet stretched over two rollers, one of which has a cog-wheel G upon the end of its axis, and receives motion from a pinion situated behind the pulley F. This pulley is turned by an endless cord passing round a pulley n, fixed upon the cog-wheel E, which is turned by a pinion 8 on the end of the axis of the great cylinder. The wool which is spread on the cloth 5 is taken off, between a pair of feeding-rollers, which are clothed with cards laid on in spiral fillets. These rollers cannot be seen, being within the frame; they are about 2½

inches diameter, and are turned round by toothed pinions on the axis of the cloth-roller, so as to move rather quicker than the feeding-cloth. The feeding-rollers give the wool to a cylinder 4 *a*, called the carrier, which is about nine inches diameter. The carrier works against the cylinder C; but as its surface moves more slowly than the surface of the cylinder, the wool contained in the teeth of the carrier is taken up by the cylinder. The carding-machine represented in our plate is shewn with a cylinder 3, beneath the carrier; this is not used in the present machines, but the feeding-rollers give the wool at once to the carrier 4 *a*.

That part of the cylinder which is adjacent to the carrier moves upwards, so as to carry up the wool it has taken from the carrier, and give it to the workers 2 *a* and clearers 2. The surfaces of the workers 2 *a* move in the same direction as the surface of the great cylinder, but they turn slowly, being put in motion by the chain 9, which passes over wheels at the ends of all the three workers. These wheels have cogs or teeth to enter into the links of the chain, and prevent it from slipping; the chain passes beneath a wheel fixed on the axis of the cog-wheel E, but within the frame. The wheel E is turned by a pinion 8, fixed on the extremity of the axis of the great cylinder; and the proportions are such, that the workers 2 *a* revolve once to about four turns of the great cylinder, and the workers being about 6½ inches diameter, whilst the cylinder is 30 inches diameter, the surface of the cylinder moves about 18½ times as fast as the surfaces of the workers.

The small rollers 2, called clearers, are placed so as to card the wool on the workers, and on the great cylinder also. The clearers are turned round very quickly, and take the wool from the workers, but their surfaces do not move so fast as the surface of the cylinder. Thus the strap 13 passes over a wheel of about 8½ inches diameter, fixed on the extremity of the axis of each clearer; this strap is put in motion by a wheel of about 22 inches diameter, fixed on the axis of the great cylinder; therefore, the clearers turn about 2½ times to one of the great cylinder; but as they are only 3½ inches diameter, and the great cylinder is 30 inches diameter, the surface of the cylinder moves near 3½ times as fast as that of the clearer. The carrier 4 *a* is turned by the same strap 13; but being larger than the clearers, its surface moves much quicker, so that the cylinder's surface moves only about once and a half as fast as the carrier's surface.

The strap 13 also turns a cylinder 2, at the right-hand end of the machine, called the fly: its surface moves the same way as the surface of the cylinder, but moves nearly once and a half as fast; the pulley at the end of the fly being only 4½ inches diameter, and the fly itself nine inches. The fly is not placed so close to the cylinder as to take the wool away therefrom, but is intended to raise and loosen it in the cards of the cylinder, so that the cylinder 4 beneath it, called the doffer, can take off the wool more readily. This doffer is 14 inches diameter, and is covered with separate sheets of card-wire, each about 4 inches wide, leaving vacant spaces between them parallel to the axis of the cylinder. The doffer moves round very slowly, its surface moving only ¼ of the velocity of the surface of the cylinder: it is turned by a band from a pulley on the axis of the roller D, which we shall next describe.

The comb which works against the surface of the doffer, and strips off the wool from it, cannot be seen in the drawing. The comb is supported by two upright rods, screwed to it one at each end; the upper ends of these rods are guided by two horizontal levers, and the lower ends are jointed to two small cranks formed on an horizontal axis, which is situated at the lower part of the frame near the

ground, and put in rapid motion by a strap, from a pulley at the bottom of the frame beneath the great cylinder. This pulley has a smaller one fixed on the extreme end of its axis, and receives its motion from the same strap 13, which turns the clearers. Every revolution of the cranks causes the comb to rise and fall about two inches; and when the comb descends, the teeth on its edge act against the cards, on the surface of the doffer 4, so as to take out the wool from them. This wool is separated in a continued sheet or film, because the strokes of the comb succeed each other very quickly, and the doffer turns round slowly; but owing to the vacant spaces between the cards on the doffer, this film only continues for a width of about four inches, and is then discontinued until the vacant space on the doffer has passed by the comb, which then acts again to strip off the wool, and so on: hence the wool is drawn off from the machine in a carded state, in small and very delicate films or webs of about 4 inches wide, and 27 or 28 inches long, which is the length of the doffer.

These detached portions of wool are next rolled up so as to form small cylindrical rolls, which is done by what is called the roller-bowl D: it is a cylinder of wood, with shallow flutes upon its surface, parallel to its axis; it is turned round slowly by a pulley H on the end of its axis, and an endless band, 14, which passes round a pulley I, fixed on the wheel E. The lower part of the roller-bowl, D, is inclosed within a hollow cylinder of wood, called the shell; it encompasses the lower half, being fixed beneath the revolving cylinder; the shell is fluted within side, but does not touch the bowl, leaving a small interval between the two. The portions of wool, as they are stripped or combed off from the doffer, fall down over the edge of the shell, which for that purpose is situated close to the doffer, at that part of its circumference where the comb works: by this means, the wool which is stripped off falls down into the space between the shell and the roller-bowl; and when the portion of wool is completely detached and drops off, the motion of the bowl within its shell rolls the wool between them with a rolling motion, which forms the wool into a very round and straight cylindrical roll, called a carding, when these cardings drop out from between the roller-bowl and its shell; they fall upon a flat table, *a a*, as shewn at 7 7 7. This table is covered with an endless cloth, which is stretched over two horizontal rollers; one of these rollers has a cross, marked 16, 16, fixed on the end of its axis; the arms of the cross are seized by a cranked lever, 15, which is fixed to the axis of the roller-bowl, and at every revolution the cross 16 is turned round one-fourth: this moves the endless cloth forwards, and carries the cardings away in the manner shewn at 7 7 7, as fast as they drop out from the shell, and from this table they are carried away to the slubbing-machine, or billy.

In most modern machines the latter movement is altered, the endless cloth being kept in a continual and slow motion by an endless band passing round a small pulley fixed to the pulley H, and a larger pulley fixed in place of the cross 16.

In some old carding-engines many of the motions were performed by toothed wheels and pinions; but of late years all the parts are moved by bands or straps, which produce a much more equable and steady movement. The large cylinders are generally made by placing two or more wheels of cast iron on one axle, the circumference of the wheels being cased with wood, which is attached to them by screws or rivets. The smaller rollers are formed in a similar manner on wooden disks, but all are made hollow, to avoid warping, which would render the action of the cards irregular and uncertain.

We must now return to the scribbling-machine : it is the same as the carding-machine, except that the breadth of the cylinder is greater, and the teeth are coarser ; there is no roller-bowl D, and the doffer 4 is completely covered with cards, without any breaks or intervals ; hence the film of wool which is taken off is continuous, and is suffered to fall down into a basket.

Double Scribblers.—In Yorkshire it is common to employ double scribblers ; that is, two of the machines combined together, and placed in one frame ; there are two large cylinders, each surrounded with its workers and clearers, and doffer, as we have described, making in all seventeen small cylinders. The first great cylinder has a feeding-cloth and carrier, to supply the wool to the cylinder ; but the second large cylinder is supplied with wool from the doffer of the first cylinder, which doffer serves in place of a carrier to the second ; it therefore has no comb. The doffer of the second cylinder has a comb to take off the wool, which then falls into a basket.

This machine is said to save trouble of attendance, and does more work than two single machines. The usual practice is to pass the wool once through the double machine, and then once through a single machine. A double machine will scribble about a hundred weight of wool per day.

After the wool is scribbled it is weighed, and when it is taken to the carding-machine, a certain weight is spread over a certain length of the feeding-cloth, so as to supply the wool to the machine with perfect regularity. The proper weight which should be allowed is ascertained experimentally, according to the fineness of the thread which is required to be spun. The cardings are weighed from time to time, to ascertain if each one contains the proper quantity of wool.

The cardings produced by the united operations of scribbling and carding are composed of fibres of wool laid very lightly together with the least possible entanglement ; they are very regular and even in size, and upon this circumstance the perfection of the spinning chiefly depends.

Slubbing-Machine, or Billy.—This performs the first process of spinning. It reduces the cardings, and draws them out in length ; joins them together, and gives them a slight twist, in order to form a coarse and loose thread, called a slubbing or roving, which must be spun over again in the jenny, to make a thread fine enough for the loom.

This operation was formerly performed by hand on the common hand spinning-wheel, which is similar to that used for spinning wool, but of a smaller size. Machines were then contrived by which a number of slubbings could be drawn out together ; but the aid of the hands was required for joining the rolls or cardings of wool together in succession, and for other purposes, which were found to take so much time, that very little, if any, saving of labour was effected by the use of such machines.

A perspective view of the slubbing-machine, now universally employed, is given in *Plate I. Woollen Manufacture*. A A is the wood frame of the machine ; within this frame is a moveable carriage, D D, which runs upon the lower side-rails at a a, with wheels 1, 2, to make it move easily ; and it is capable of running backwards and forwards in the frame from one end to the other. The carriage contains a number of perpendicular spindles, marked 3, 3, which are put in rapid motion by a long cylinder F, and a separate band from each spindle, which passes round a small pulley on the spindle. The cylinder F extends horizontally across the whole breadth of the carriage ; it is made of tin plate, hollow like a tube, and covered with paper on the outside.

The spindles are placed in a frame, so as to stand nearly perpendicular, at about four inches from each other ; their

lower extremities are sharp-pointed, and turn in sockets, and they are retained in their perpendicular position by a small collar of brads for each, which surrounds the spindle at about the middle of its length. The upper half of each spindle projects above the frame, and on the lower part the small pulley or whirl is fixed, to receive the band from the horizontal cylinder, which is about six inches in diameter, and a little longer than the row of spindles ; it is placed before them with its centre at a lower position than the row of whirls. The cylinder receives motion by a pulley at one end, with an endless band from a wheel E, made like the large wheel used in spinning wool by hand, and of the same dimensions. The wheel is situated at the outside of the great frame of the machine, and its axis is supported by upright standards erected from the carriage D ; the wheel is turned by the left-hand of the spinner, applied to a winch, which is plainly seen in the drawing, and gives motion to the cylinder F, which again turns all the spindles at once with a great velocity.

Each spindle receives a thread, or slubbing, which threads issue from beneath a roller, C C, at one end of the frame, and proceed to the row of spindles placed in the carriage, so that the slubbings are extended nearly in an horizontal direction. The spindles, by the motion of the carriage, are capable of advancing or retreating from the roller C, so as to extend any required length of slubbing.

The cardings of wool, which are to be spun into slubbings, are extended side by side upon an endless cloth, which is strained in an inclined position between two horizontal rollers, one marked B B, and the other cannot be seen. There is one carding for each spindle, and the number is usually from 50 to 80. C is a light wooden roller to bear upon the cardings which lie upon the cloth, and press slightly upon them by its weight. Immediately before this roller is a wooden rail G, and another beneath it, which is fixed horizontally across the frame : the cardings are conducted between these two rails, the upper of which is capable of rising ; but when it falls by its weight, it holds the cardings fast between the two, and hence these rails are called the clasp ; the upper moveable rail G of the clasp is guided between sliders, and a wire 7 descends from it to a lever 6. When the carriage D is wheeled close home to the end of the machine, a wheel 5 lifts up the end 6 of the lever ; and this, by the wire 7, raises the upper rail G so as to open the clasp, and release all the cardings : in this state, if the carriage is wheeled or withdrawn back from the clasp, it will draw the cardings forward. There is a small catch which receives the upper rail G of the clasp, and bears it up from falling until the carriage has retreated a certain distance, and drawn out about eight inches length of the cardings ; a stop on the carriage then comes against the catch and withdraws it ; the upper rail of the clasp G then falls and holds the cardings fast, whilst the carriage continues to recede, and draw out or stretch that portion of each carding which is between the clasp and the spindle. All this time the wheel is turned to keep the spindles in motion, and give twist to the cardings in proportion as they are drawn out, by which means it is prevented from breaking ; because as the carding diminishes in size, and increases in length, the increasing twist combines the fibres of the wool, so as to give strength to the coarse thread or slubbing which is thus produced.

The slubbing is lapped round the spindle, but the clasp being higher than the upper ends of the spindles, the direction of the slubbing is not quite at right angles to the spindle ; hence the spindle, when it is turned round, will give twist to the slubbing, without winding or gathering it

up upon the spindle, because the slubbing always slips over the top-end of the spindle; but when a portion of each slubbing is finished, and it is required to wind it up round the spindle in a ball, the slubbing must be pressed down by a wire 8, so as to bear it from the point of the spindle, and place it opposite to the middle part of the cop or ball upon the spindle, and then the motion of the spindle will cause it to wind up upon the spindle, and form a ball.

The wire 8 is made to operate upon the whole row of slubbings at once, and for this purpose a horizontal rail 4 is placed in the front of the row of spindles, being provided with pivots at its extreme ends, on which it is supported in standards rising from the carriage D. It has a small arm or lever projecting from it at each end, and the wire 8 is stretched between these arms. By turning the rail 4 round upon its pivots, the wire is capable of being raised up, as in the figure, or lowered down at pleasure: when the wire is lowered, it descends below the level of the top of the spindles, so as to bear down the threads which, when the wire is raised up, as shewn in the figure, proceed from the points of the spindles.

The spinner holds the rail 4 in his right-hand, and it is by this that he draws the carriage either in or out, according as it may require; and by turning the rail 4 round, he can elevate or depress the wire 8, so as to make it bear down the slubbings to any degree at pleasure; by this means, he distributes the slubbings upon the spindles in a proper manner, to form a regular ball or cop, as shewn in the figure.

As the cardings are very slight and tender, they would be liable to break if they were dragged forwards on the inclined cloth, or even if the cloth were to be moved round its roller by the force applied to the cardings. To avoid this, a cord is applied round a groove in the middle part of the upper roller, and after passing over proper pulleys, as shewn in the drawing, it has a weight suspended to one end, and a smaller weight to the other; the small weight is only to keep the rope tight, but the large weight tends to turn the rollers and endless cloth round in a direction to deliver out the cardings, so that there will be no strain on them. Every time that the carriage is wheeled home, the large weight is wound up by means of a piece of wood projecting from the carriage, which seizes a knot in the cord at the part which lies horizontally; this pushes the cord back a certain distance, so as to draw up the great weight; but the endless cloth cannot turn backwards, because there is a ratchet and click at one end of the roller which prevents it; the rope, therefore, slips round upon the roller. When the carriage retires, the great weight turns the roller and endless cloth round, so as to deliver out the cardings at the same rate as the carriage retreats and takes them up; but when the proper quantity is given out, the knot in the rope arrives at a fixed stop, which does not permit it to move any farther; and at the same instant the roller 5 quits the lever 6, and allows the upper rail G of the clasp to fall, and hold the carding fast from being drawn out any farther; the wheel E is then put in motion to turn the spindles round, and the carriage is drawn back, which extends the slubbings, and twists them at the same time, as before mentioned.

When the carriage is drawn out to its full extent, and the necessary twist is given, the wire 8 is put down to bear down the slubbing from the point of the spindle, and the motion of the wheel being continued, the slubbings are wound up upon the middle part of the cop or ball which is formed upon the spindle; but as fast as the slubbings are wound up, the spinner must push back the carriage towards the clasp; and he must turn the wheel round at such a rate that the

spindles will not wind up any faster than the carriage returns, otherwise the slubbings would be broken or unequally stretched; he must also raise and lower the wire 8 continually, by turning the rail 4 round in his hand, in order to distribute the slubbing on the cop in a regular manner, so as to make a firm ball or cop.

A child attends the machine to bring the cardings from the carding-machine, and place them upon the inclined cloth; and when they are exhausted, fresh ones are joined on, so as to keep the machine constantly supplied.

The degree of twist which is given to the slubbing is regulated by the discretion of the spinner in turning the wheel at a proper rate, corresponding to the quickness with which he draws out the carriage. Slubbings which are intended to be spun into yarn for the warp of the cloth require to be more twisted than the slubbings intended for the weft; but the proper quantity of twist depends on the fineness of the wool, and the length of its fibres. In general it may be stated, that no more twist is given to the slubbings than is necessary to make them draw out to the required extent without breaking. This twist is of no use to the yarn, because the slubbing will be twisted in the contrary direction, when it is spun the second time in the jenny.

An improved slubbing-machine has been introduced, which is put in motion by the mill, and the carriage is made to draw out by the power of the machine. The spinner has only to push the carriage in, and turn the handle, in order to wind up the slubbings; by this means, a greater degree of regularity is attained in the quantity of twist which is given to the slubbings when they are drawn out. The movements to effect this are taken from the mule used in cotton-spinning. See *Manufacture of COTTON*.

Spinning Jenny.—In this machine, the slubbings are spun over again, and reduced to the requisite fineness for weaving. The jenny has nearly the same parts as the billy, but differently arranged. The spindles are placed at one end of the frame, and the clasp which holds the slubbings is placed on the carriage, so that it can be moved backwards and forwards, to and from the spindles by the spinner, in order to draw out and extend the yarn at the same time it is twisted.

A perspective view of the jenny is given in *Plate II. Woollen Manufacture*.

The spindles 3, 3, 3, are placed perpendicularly at about four inches asunder at one end of the frame A A of the machine. The lower extremities of the spindles are pointed, and turn in small cups or sockets in a cross-rail of the frame; they are supported near the middle of their length by passing through brass-collars in a horizontal rail. Near the lower end of each spindle a small pulley is fixed, to receive an endless band, which passes round the horizontal cylinder or roller 2, about six inches diameter. The cylinder is supported on pivots at its ends in the sides of the frame, and lying in a direction parallel to the row of spindles, it turns them all round by a small band for each. This cylinder is usually made of tin-plate, that it may not alter its figure by the weather, as wood would do; and its surface is covered with coarse brown paper, to prevent the bands from slipping upon it. The cylinder 2 is put in motion by a strap or band 1, 1, which passes round a pulley at the end of it, and also round the great wheel B B, which is supported in a framing suspended over the machine from the ceiling, but which is not shewn in the drawing. The wheel B is turned by applying the right-hand to the winch B. In front of the row of spindles, and about a foot higher than their points, a long cross-rail 16 is situated horizontally: it is supported at each extremity by being mortised into blocks of wood c c, which are furnished

with small wheels or castors, forming a sort of carriage, to run horizontally upon the side-beams of the main-frame in grooves, which guide them, so that the rail 16 can be moved backwards and forwards through a space of about six or seven feet, in a horizontal position, without varying from its parallelism with the row of spindles. The under-side of the rail 16 is formed into a number of narrow notches for the slubbings to pass through; and these notches are partly filled up by projecting pieces, rising up from a second cross-rail 5, so as to form the clasp which confines or pinches the slubbings in the notches when the lower rail is raised up; but the slubbings can draw freely through the notches when the lower rail is let down. This lower rail is guided and limited to move up and down only a small space by staples, which project downwards from the rail 16, and receive the ends of the lower rail 5 of the clasp. The rising and falling of the lower rail is effected by small cords fastened to it at about every yard of its length; these cords are conducted over small pulleys (concealed in the substance of the upper rail 16), and are all attached to a handle, situated over the middle of the upper rail at 16, and beneath an arched bar, which is fixed on the top of the clasp. The spinner holds this handle in the left-hand, whilst the right is employed in turning the wheel; and by the fingers of the left-hand she can raise up the lower rail 5 of the clasp, and draw it close to the upper one. It will then be retained in that position by a small spring-catch, and will clasp the slubbings fast in the notches, through which they pass; but when the spring-catch is pushed back, so as to relieve the handle, the lower rail will fall down by its own weight, and release the slubbings, to allow them to slide through the notches.

The cops of slubbings which are to be spun are supported in an inclined frame 4, 4, fastened within the main frame of the machine. The cops are mounted upon iron wires; they are placed in two rows, one above the other, as shewn in the drawing; but each row should only contain half as many cops as there are spindles.

Each slubbing is conducted through a notch in the clasp, and thence it proceeds nearly in an horizontal position to the spindles 3, 3.

When the yarns have been drawn out and twisted they are wound up on the spindles in balls, in a similar manner to the billy. The wire which is used for bearing down the thread from the points of the spindles is marked 12; it is attached to a horizontal rail, which is supported on pivots at its ends, close to the row of spindles. There is a small pulley 11, fixed at one end of the rail, and a short lever at the other, which lever is hidden in the drawing by a part of the framing. Between the pulley 11 and the lever, the wire 12 is extended, and by turning the rail round upon its pivots, the wire will have a motion up or down.

The spinner can communicate motion to the pulley 11 by means of a cord 7, 7, which passes round it, and extends the whole length of the frame, the end being made fast to a pin at A; this cord lies over the surface of one of the blocks c, which contains the wheels of the carriage, and passes between three small pulleys 9, 6, and 8. The centre pins of the pulleys 9 and 8 are fixed to the block; but the centre pin of the pulley 6 is fixed to a small slider, and can be drawn in the direction of the rail 16, by applying the finger to a small trigger near the handle 16. This action removes the pulley 6 out of the line of the other two pulleys, so as to shorten the cord 7, and turn round the pulley 11; this brings down the wire 12, and bears down the threads upon the spindles. A small counterweight is suspended from the wheel 11, to return the wire to its former position when the pressure of the finger on the trigger is removed. By

this movement, the spinner has full command of the wire 12, to raise or lower it in any degree she thinks proper; and this is done independently of the motion of the carriage, because the pulleys 9, 6, and 8, run freely along the cord 7, and their motion has no tendency to move the wheel 11 either way.

The jenny is worked by one person, who stands within the frame, and turns the wheel B with the right-hand, whilst he holds the clasp in the left, so as to run it backwards and forwards along the frame at pleasure. The slubbings are drawn between the moveable rails 16 and 5, in the notches of the clasp, and each slubbing is fastened on to its corresponding spindle. The clasp being left open is drawn backwards from the spindles, and the slubbings run freely through the notches of the clasp; the slubbings are drawn off the balls at 4, when the clasp retires from the spindles, until a certain length of each slubbing is drawn out and extended nearly in an horizontal position between the spindles and the clasp: this length is regulated by a mark made on the frame of the machine, to indicate when the clasp has arrived at its proper position. The bars of the clasp are then brought together by raising up the handle under the catch, as before described, and it fastens all the slubbings in the notches. This being done, the spindles are put in rapid motion by turning round the large wheel B B; they twist those parts of the slubbings which are extended, and the motion being in a contrary direction to the twist of the slubbing, the first tendency is to untwist the slubbing, at the same time that the carriage and clasp are gently drawn back, or from the spindles. By this means, the slubbings are stretched or drawn out in length at the same time that they get a new twist in the opposite direction; this keeps them from breaking, and when they are drawn to their intended extent by the carriage being moved back to the stops at the extremity of the main frame, the great wheel is turned round as many turns as is necessary to give them all the twist which those portions of thread are intended to have.

The threads extended between the clasp and the spindles are now finished, and it only remains to wind them up upon the spindles, previously to drawing out a fresh portion of each slubbing, in order to spin it in the same manner. To wind up the threads, they are pushed down upon their respective spindles, by pressing the trigger which moves the wire 12; and the motion of the great wheel B is continued, in order to wind up the slubbings in balls upon the spindles, at the same time that the carriage and clasp are pushed back towards the spindles. When the carriage is got home, the thread is finished and wound up, and a fresh portion of slubbing is extended. To do this, the lower rail of the clasp is dropped down, and it releases the slubbings; the carriage is then drawn back to the mark upon the frame, as before described, which shews that a proper length of each slubbing is drawn off from the balls, and extended between the spindles and the clasp. The clasp is then closed, and the wheel B put in motion to twist the threads whilst the carriage is drawn out; thus the spinning operation is repeated as before, and prepares another length of each of the threads. When finished, they are pushed down from the points of the spindles, in order to make them wind up thereon in the balls, as before.

There is some discretion required in spinning with the jenny, to draw out the carriage with a movement correspondent to the rapidity with which the spindles give the twist, or rather untwist, to the slubbing; for the principal extension of the thread is effected whilst the slubbing is untwisting, and whilst the first portion of twist is given to the threads. These motions must be properly proportioned by

the spinner, who must also be careful to give an equal degree of twist to each successive portion of thread which is spun, otherwise the thread will consist of hard and soft places.

When the yarn is intended for the warp of the cloth, the spindles are turned for a given time after the thread is extended to its full length, as we have before mentioned; but for the yarn which is to be used as weft, it is different: the whole of the twist is given during the extension of the thread, and none afterwards; this difference is to render the weft softer than the warp, because in the cloth the weft appears more on the surfaces than the warp, and it is principally the felting and interlacing of the fibres of the weft that will form the surface of the cloth when finished.

The yarns are usually extended in the jenny two and a half or three times the length of the slubbings from which they are spun; and that degree of twist given to them which is suitable to the purpose for which the yarn is to be employed.

The *Mule for spinning of Yarn* is very nearly the same machine as the mule for spinning cotton; this is used for spinning some kinds of woollen yarn instead of the jenny. When the mule is employed for spinning yarn for weft, it is used in the same manner as described in our article *COTTON MANUFACTURE*; but for spinning warp, the spindles are made to revolve, and twist the thread some time after the carriage is run completely out, and the stretching of the yarn is finished. There is a movement in the machine that shifts the endless strap which turns the mule upon a larger pulley, as soon as the carriage is run fully out, so as to give a more rapid motion to the spindles after the stretching, or drawing out, is finished, than they had during the drawing back of the carriage. By this means some time is saved, because the spindles may be allowed to run very quick when it is only required to twist the threads; but whilst the extension is going on, the twisting motion must be moderate, or the threads would be broken. A very similar movement is used in the mule for spinning cotton, and is called the double-speed; but the description of this mechanism is omitted in the article *MANUFACTURE*.

The mule has not, till lately, been in much repute for spinning woollen yarn, and the jenny is still thought to spin better yarn: but we have no doubt that when certain modifications are made, it will become a much more perfect method than the jenny, being much less dependent on the dexterity and dexterity of the spinner; for if the machine is once constructed so as to spin properly, it will always continue to do so.

To keep the yarn to the size which is intended, a few of the coppins are reeled off, in order to measure out a certain length of the yarn, which is weighed; and if it does not prove of the weight expected, the quantity of wool which is spread over a given surface of the feeding-cloth of the carding-machine must be increased or diminished accordingly; and when the right quantity is formed, the lead weights which are used for weighing the given quantity of wool are altered to suit it. The draft of the jenny may also be altered to effect the same thing.

The spinning processes are now finished, and it remains to weave the yarns into cloth. From the description we have given, it will appear that woollen yarn is spun in a very different manner from cotton. The opening processes and the scribbling and carding are very similar, except that the carded wool, instead of being drawn into a continued sliver like cotton, with the fibres stretched the lengthways of the sliver, is formed into separate rolls, with the fibres disposed crosswise or spirally round the roll.

By the slubbing-machine these are joined together, drawn

out in length, and slightly twisted, by operations similar to that of roving in cotton-spinning; but the operation of drawing, which is so frequently repeated for cotton, would be useless, and to a certain extent even prejudicial for wool. The object of that process is to elongate and stretch the fibres of the cotton straight, and lay them parallel to each other; but it does not reduce the sliver to a smaller size, because as many times as the sliver is extended in length, so many slivers are put together into the drawing-frame at once, leaving the sliver which has been drawn the same size as it was before, but elongated to three or four times the length, and all its fibres fully extended.

As woollen cloth is intended for felting, it is not desirable to straighten the fibres, but only to disentangle all knots, and unfold any fibres which may be doubled, also to lay the fibres in the direction of the length of the thread. There is a natural curl in the fibres of wool which should be preserved, and will contribute to the firmness with which the fibres will entangle in the felting.

The operation of spinning by the jenny and billy are very similar, but both differ from the manner in which the extension is made in the cotton spinning-machines by rollers. In the jenny, the extension is made upon a considerable length of the carding or slubbing at once; but in the rollers, the length of cotton which is submitted to the action of drawing out is very short, indeed very little longer than the length of the fibres of the cotton. In mule spinning both modes of extension are practised; first, drawing the roving by rollers, and then a certain length is stretched out to a greater extent.

Warping.—The coppins of yarn are mounted on wires in a frame, and the yarns are drawn off from them, in order to combine a sufficient number of them together, to form the warp for the web of cloth which it is intended to weave. For instance, for making the cloth called double drab, which we shall take as an example, 2960 threads, each 65 yards long, are laid parallel to each other; but a separation is preserved at every 40 threads, dividing the whole into 74 parcels, for the convenience of the weaver.

The warping is performed by the warping-mill, which is a large reel, with its axis horizontal; the ends of the threads are made fast to the reel, which is turned round, and it draws the threads off the coppins, so as to wind them upon its circumference; and to prevent the different turns of the threads from lying one over another, the threads are guided through an eye or ring affixed to a slider, which is moved along a wooden rail, in a direction parallel to the axis of the reel, by a cord that winds round one end of the axis of the reel.

A warping-mill for silks is described in our article *SILK*, and will give a clear idea of the present, which only differs in the horizontal position of the axis, and in the greatness of its dimensions. The threads for the warp being thus assembled together, are taken off the reel, and rolled up into a bundle.

The warp is then scoured in urine, to remove the greasiness of the wool, and is next sized; to do this, it is dipped into the cauldron of size, about ten yards in length at a time, and well worked in by the hands. After sizing, the yarns are stretched out at length in a field, till they are dry, and the warp is then ready for the loom.

The yarn for the weft is wound off from the cops of the jenny to the quills or small bobbins, which are to be put into the shuttle.

The loom for weaving broad-cloth has the same parts as the simple loom described in our article *WEAVING*; but it is made very strong, to enable it to resist the strain of weaving

such broad and heavy cloth. The fly-shuttle, invented by John Kay in 1737, is now in general use; it enables one weaver to do the work, which formerly employed two men at opposite sides of the piece, to throw the shuttle from one to the other, the width being greater than a man can reach. The warp is wound on the yarn-beam, which is placed in the loom, and the threads being drawn through the heddles and the reed, and fastened to the cloth-beam, the loom is ready for working, in the usual manner of weaving plain cloth. At each edge of the warp a few threads of strong and coarse yarn are placed; these form what are called the lifts when the cloth is woven, and serve to give strength to the cloth, and receive the hooks by which the piece is stretched in the tenters after milling.

The width of the cloth is measured between the lifts and the number of yarns, which we have specified will make 100 inches in width for the double drab-cloth, or for common cloth 3000 threads will make a piece 103½ inches wide. The quantity of weft used for these cloths is upon an average one pound weight to a yard in length. The length of the warp contracts a little in the weaving, so that the sixty-five yards of yarns will make only sixty-two yards of cloth.

Scouring.—The piece of cloth must be cleaned from the greasiness of the oil before it can be felted; for this purpose, it is first soaked three hours in a mixture of urine and pig's dung, it is then scoured in the mill for two hours, and lastly, for half an hour with fair water. The scouring is performed at the fulling-mill by a pair of stocks. (See *FULLING-Mill*.) The pair of stocks are two large wooden hammers, suspended with the helves or handles in an inclined position, and the heads are lifted in succession by cogs or tappets, fixed on the axis of a water-wheel. When the cogs quit the hammers, they fall by their own weight, and strike the piece of cloth, which is contained in a wooden cistern or trough, in which the hammers work. The action of the hammers is to beat and compress the folds of cloth, and to turn the piece continually round in the trough or cistern in which it is placed. The form of the trough is such, that the weight of the piece of cloth causes it to occupy the lower part of the trough, and each hammer when it descends drives the cloth out from this lowest part, and forces it up a curved sweep. When the hammer is lifted up, the cloth falls again into the space which it before occupied, and at the subsequent descent of the hammer it is again driven out; the heap of cloth is of a considerable bulk, and this action of the hammers is chiefly on the lower part of the heap; the beaks of the hammers strike nearly horizontally under it, as it were to undermine the heap, so that the top part falls over when the hammers retreat. This action causes a continual circulation or turning round of the piece of cloth within the trough, and effects the scouring, by continually bending and folding the cloth in a fresh direction; and as the strokes act upon a great number of folds at once, the different surfaces of the cloth are caused to rub against each other, with a very similar action to washing cloth by hand.

When the scouring is finished, the piece of cloth is taken out, and extended in a vertical plane, in a frame called the tenter, where it remains till dry.

The *tenter* consists of a number of vertical posts fixed in the ground with a continued horizontal rail, which is fixed on the top of them, and is as long as the piece of cloth; there is also another line of horizontal rails, which are fitted between the upright posts, so as to slide freely up and down; and they can be fixed at any distance beneath the upper rails by means of pins in the posts, according to the width of the piece of cloth. Both the upper and lower horizon-

tal rails are driven full of tenter-hooks, which are small iron rails sharpened at both ends, and bent at right angles, like an L; on these hooks the lifts of the cloth are fastened, and the lower or moveable rails are fixed at the proper distance beneath the upper rails, in order to extend the cloth to its full width.

Burling.—The cloth being dried is burlled, that is, examined minutely in every part, and all knots and uneven threads or straws, or extraneous matters, removed; any rents or defects which can be found are repaired, by introducing fresh threads. This being done before the milling or felting, the fibres of the new threads will become so entangled as to render such defects nearly imperceptible in the finished cloth.

Fulling-Mill for felting the Cloth.—There is another kind of stocks in a fulling-mill; but the shape of the trough in which the stocks or hammers work on the cloth is different from that described in the article *FULLING-Mill*, which is only proper for scouring. In order to subject the cloth to the blows of the hammers, the trough for milling is formed in such a manner that the cloth cannot escape from them, because that part of the trough which is opposed to the beaks of the hammers is nearly a flat surface, and perpendicular to the direction in which the hammers strike, so that the cloth is actually beaten between the beaks of the hammers and the flat bottom or rather side of the trough.

The hammers are made to strike very heavy blows; but they do not bruise or injure the cloth, because there is always a great number of folds of cloth on which they strike. The helves or handles of the hammers are placed in a different position from the scouring-stocks, in order to make the hammer-heads fall in a more perpendicular direction when they make their stroke, and hence they strike with more force. On this account they are called falling-stocks, whilst those used for scouring are called hanging-stocks, in which the helves of the hammers being nearer to the perpendicular, the heads move in a more horizontal direction, in the manner of a pendulum, and exert less force on the cloth; the other difference is, that the hammers of the scouring-stocks only drive the heap of cloth round in the trough, there being no part directly opposed to the beaks of the hammers but a fair curve, which is so much inclined to the direction in which the hammers move, that the cloth mounts up the inclined curve when the hammer strikes, and evades the direct force of the blow.

There is another kind of fulling-stocks, in which the trough and hammer are constructed with a view to mill or felt the cloth; but the hammers are put in motion in a different manner: thus the helves are suspended in a vertical position, like pendulums, and the force of the cogs on the horizontal shaft, which is turned by the water-wheel, is applied to drive the hammers forwards against the cloth, and produce the felting. To return or draw back the hammers, a chain is attached to each, and these chains are linked to the opposite ends of an horizontal lever, like a scale-beam, which is fixed in front of the stocks. This lever and chains draw back one hammer when the other is pushed forwards; and as the hammers are actuated alternately by the cogs, a constant action is kept up.

The most simple fulling-mill by a water-wheel has no other wheels, but the tappets or cogs which lift the hammers are fixed immediately into the axis of the water-wheel, and it usually gives motion to two pair, one at each side of the wheel. It rarely happens that this construction of a mill allows the water to be used to the greatest advantage, because the circumference of a water-wheel should not move with a greater velocity than between 180 and 240 feet per

minute; and the hammers of a fulling-mill should be so timed, that each one will make from about 30 to 36 blows *per* minute. This requires that the cogs for the hammers should be numerous, and fixed in the circumference of a large wheel fixed on the axis of the water-wheel, otherwise the water-wheel must be made to turn so quickly as to lose a great part of its force. A better way is to apply a cog-wheel on the axis of the water-wheel to turn a pinion on the horizontal shaft, which carries the cogs for the hammers, and this horizontal shaft may have a fly-wheel upon it, to regulate the motion and render it uniform.

Mr. Smeaton's proportions for a fulling-mill for two pair of stocks were as follows:—The water-wheel, 14 feet diameter, 7 feet broad; it was a breast-wheel, and the fall of the water was five feet from the surface of the mill-pond to the tail-water below. The spur-wheel on the axis of the water-wheel 72 cogs, and 9½ feet diameter; the lantern turned by it 23 rounds. Upon the same shaft as this lantern was a fly-wheel of eight feet diameter, with a rim of cast-iron seven inches square, and also the two cogs or tappets for each of the four hammers forming two pair of stocks. The same mill was adapted to be turned by the power of horses in dry seasons; for this purpose, another lantern of 13 teeth was applied on the other end of the same horizontal axis, which could be occasionally turned by a horizontal cog-wheel of 90 teeth and 12 feet diameter, fixed on the vertical shaft, which the horses turned. The levers by which the horses drew were 15 feet long, so that the horses' track was 30 feet diameter.

It required four horses to work one pair of stocks in this mill, and when Mr. Smeaton tried the expenditure of water at this mill, and also at another mill with an overshot-wheel, he found it required from 1200 to 1400 cubic feet of water *per* minute, falling one foot, to work a pair of stocks. Taking the force of a horse at 352 cubic feet *per* minute raised one foot, this is very nearly equal to four horses. These stocks were used for fulling of bays, and we apprehend the power for working the fulling-mills for broad-cloth is greater.

Process of Milling.—A piece of cloth of sixty-two yards long has six pounds of soap allowed for it, which is dissolved in water, and a handful spread upon every yard in length; the piece is then put into the trough of the mill, and worked for three hours; during this time the cloth is frequently moved in the trough, to expose fresh surfaces to the action of the hammers. The blows upon the cloth cause a motion of the fibres of the wool amongst one another, and the soap facilitates this motion; the fibres of the wool have the singular property of moving always forwards in the direction of the roots of the hairs, when a number of hairs are rubbed or worked together, but they will not retreat in the opposite direction; this produces the matting or entangling of all the fibres together. After three hours milling, the piece of cloth is taken out of the trough, and soaped again, then returned and milled again for three hours. This is repeated four times, making twelve hours milling in the whole, and then a stream of fair water is admitted into the trough, to wash away the soap. The piece of cloth, when taken out of the mill the last time, is generally found reduced to about 60 inches broad, and 40 yards in length; before the operation, it was 100 inches broad, and 62 yards in length.

The operation of felting is so well explained by M. Monge, in the *Annales de Chimie*, that we think proper to give an extract from his memoir, in addition to what is stated in our articles *FELTING*, *FULLING*, and *WOOL*.

If we examine a human hair, a fibre of wool, or the hair of a rabbit, hare, beaver, &c. in a microscope of the greatest

magnifying power, the surface of each hair appears smooth and even; or at least if any inequalities are perceptible, they seem rather to arise from some difference in the colour and transparency of particular parts of the fibres than from the irregularity of their surfaces; for their images, when viewed by a solar microscope, are terminated by even lines, without any roughness. Nevertheless it is probable the surfaces of these objects are formed either of *laminae*, which cover each other from the root to the point, much in the same manner as the scales of a fish cover the animal from the head to the tail; or still more probably of zones placed one over the other, like what is observed in the structure of horns; to this conformation it is, that such substances owe their disposition to what is called felting.

If with one hand we take hold of a hair by the roots, and draw it between two fingers of the other from the root towards the point, we are hardly sensible of any friction or resistance, nor can we distinguish any sound; but if, on the contrary, we draw it between the fingers from the point towards the root, we are sensible of a resistance which did not exist in the former case. A sort of tremulous motion is also produced, which is not only perceptible to the touch, but may also be distinguished by the ear.

It is evident, therefore, that the texture of the surface of a hair is not the same from the root towards the point, as from the point towards the root. As this texture is the principal object of the present memoir, it is necessary to demonstrate it by some other observations.

If a hair is held between the fore-finger and thumb, and rubbed by them backwards and forwards alternately in the direction of its length, a progressive motion of the hair will take place; but this motion is always with the root forwards, although the rubbing of the finger and thumb is alternately in both directions. This effect does not at all depend on the nature of the skin of the fingers, or its texture; for if the hair be turned, so that the point is placed where the root was, the movement then becomes contrary, *viz.* its motion is always directed towards the root.

What is observed in the above instance is entirely analogous to what happens when country children, by way of sport, introduce an ear of rye between the wrist and the shirt-sleeve; the points of the beards of the ear are directed outwards, and by the various motions of the arm, this ear, sometimes catching against the shirt, sometimes against the skin, takes a progressive motion backwards, but the beards always resist its return, so that it soon gets up to the arm-pit. It is very clear, that this effect is produced by the asperities upon these beards, which being all directed towards the point, do not permit the ear to move in any other direction than towards that part which was united to the stalk. There can be no doubt that it is the same with respect to hair, and that its surface is beset with asperities, which being laid one upon the other and turned towards the point resist all motion, except towards the root.

These observations, which it would be useless to multiply, relate to long hair, which have been taken as examples; but they apply with equal propriety to wool, furs, and in general to every kind of animal hair. The surface of all these is, therefore, to be considered as composed of hard *lamellae* placed one upon another, like tiles, from the root to the point; which *lamellae* allow the progressive motion of the hair towards the root, but prevent a similar motion towards the point.

From what has been said, it will be easy to explain why the contact of woollen stuffs is rough to the skin, while that of cotton or linen cloths is smooth: the reason is, that notwithstanding the flexibility of each particular fibre, the as-

perities upon the surface of the fibres of the wool, by fixing themselves in the skin, produce a disagreeable sensation, at least till we are accustomed to it; whereas the surface of the fibres of hemp or flax, of which linen is made, being perfectly smooth, do not cause any such sensation. It is also probable, that the injury arising to wounds or sores from the application of wool does not proceed so much from any chemical properties, but is occasioned solely by the form of the surface of the fibres, the asperities of which attach themselves to the raw and exposed flesh, which they stimulate and irritate to such a degree as to produce inflammation.

The asperities with which the surface of wool is every where surrounded, and the disposition which it has to assume a progressive motion towards the root, renders the spinning of wool and making it into cloth difficult operations. In order to spin wool and afterwards to weave it, we are obliged to cover its fibres with a coating of oil, which, filling up the cavities, renders the asperities less sensible; in the same way as oil, when rubbed upon the surface of a very fine file, renders it still less rough.

When a piece of cloth is finished it must be cleansed from this oil, which, besides giving it a disagreeable smell, would cause it to soil whatever it came in contact with, and would prevent its taking the colour which is intended to be given to it by the dyer. To deprive it of the oil it is scoured at the fulling-mill, by working it with hammers in a trough full of water or urine, in which fuller's-earth is sometimes mixed. This earth combines with the oil which it separates from the cloth, and both together are washed away by the fresh water, which is afterwards brought to it in the machine. Thus after a certain time the oil is entirely washed out of the cloth.

The fulling, which succeeds the scouring of the cloth, is aided by the application of the soap. The alternate pressure given by the hammers to the piece of cloth, especially when the milling is pretty far advanced, occasions an effect analogous to that which is produced upon hats by the hands of the hatter; the fibres of wool which compose one of the threads, whether of the warp or the weft, assume a progressive movement with their roots forwards, and introduce themselves among the fibres of the threads nearest to them, then into those which follow; and thus by degrees all the threads, both of the warp and the woof, become felted together. The cloth, having by the above means become shortened in all its dimensions, and thickened in its substance, partakes both of the nature of cloth and of that of felt; for at the same time that the threads give it considerable strength, it may be cut without being subject to ravel, and on that account we are not obliged to hem the edges of the pieces of which wearing apparel is made. Lastly, as the threads of the warp and those of the weft are no longer so distinct and separated from each other as to leave interstices between them, the cloth forms a warmer clothing, independently of its having acquired a greater degree of thickness. Knit worsted is also rendered less apt to run, in case a stitch should drop, by the operation of fulling.

Tentering.—When the milling is finished, the cloth is stretched again on the tenter. It is usual to extend the piece to forty-two yards in length, but not at all in breadth; indeed only one inch of extension in each yard is allowed by law. The cloth remains in the open air until it is perfectly dry and ready for the succeeding operations of finishing, which are only intended to give it a beautiful surface, for it already possesses all the useful qualities of cloth.

Dressing the Cloth with Teafels.—This operation is to raise up the nap or loose fibres on the surface of the cloth, by

scratching it over with a species of thistles called teafels, in order to form a wool on the surface, which can be removed by shearing. The teafels are the balls or ears which contain the seed of the plant called *dipsacus fullonum*; the scales which form the ball project on all sides, and are terminated with sharp points, which turn downwards, like hooks, and are very elastic. See TEASEL.

A number of teafels are put into a small frame, which is composed of a handle eight or ten inches long, having a small stick passed through it at one end about eight inches long, which is split into two at each end nearly all its length. There is also another similar stick, which is passed through the handle near the middle of its length; the two split sticks are perpendicular to the stem or handle, and parallel to each other. The space between them is filled with teafels, which are jammed in very fast between them, and also in the clefts of the split sticks, where they are secured by strings extended between the ends of the split sticks, and twisted, until they draw the sticks forcibly together, and bind the teafels very fast. This frame filled with teafels forms a tool, which very much resembles the curry-comb used to clean horses, and is used in a similar manner, to scratch over the whole surface of the cloth, and draw out all loose ends of the fibres of the wool, which are not firmly confined by the entanglement of the felting.

The dressing is performed by two men, who hold the teasel-frame by its handle, and work the cloth, when it is hung up in a vertical position over two rails fixed to the ceiling; when they have worked over as much surface as they can reach, they draw down a fresh portion, which they work in turn, and thus proceed until they have finished the whole piece. The first time the cloth is dressed it is wetted with water; it is worked three times over in the wet state, by strokes in the direction of the length of the piece, and then it is worked again three times in the other direction; by this means all the fibres are raised, and the cloth is prepared for shearing.

In the most improved manufactories, the dressing is performed by the gig or gig-mill. This is a cylinder covered on its surface with teafels, and turned rapidly round whilst the cloth is drawn over it.

The *Gig-mill* is represented in perspective in *Plate V. Woollen Manufacture*. M is the wood frame of the machine; FF is the cylinder or drum, which is composed of 12 rails or troughs, filled with teafels FF, 3, 4, &c. These are fastened on the circumference of two or three wheels fixed upon a wooden axis 7; the drum is put in motion by a pulley ED at one end of its axis, which receives an endless strap, 2, from the drum C, situated above the machine. There are two pulleys, E and D, one fixed fast on the axis, and the other fitted on loosely, with liberty to turn round freely upon it; the strap can be shifted to either pulley, and accordingly the machine will be put in motion, or will stand still.

The drum C is fixed on one end of an iron shaft 1, which is put in motion by a bevelled wheel B, from the larger wheel A, fixed on the great horizontal shaft, which proceeds the whole length of the mill. The drum, FF, covered with teafels, is mounted on bearings supported by the frame, and the piece of cloth G is conducted over it, to receive the action of the teafels; one end of the piece of cloth is wound round a roller J, and the other end of the piece is wound on the roller L; both these rollers are put in motion from a bevelled wheel 6, fixed on the extremity of the axis of the drum; this turns a wheel H upon an inclined axis, which has a pinion at each end; one of these pinions, 9, turns a bevelled wheel, K, on the end of the axle of the upper

roller L; and the other, 8, turns the wheel I belonging to the lower roller J. By means of this wheel-work both rollers are turned round in the proper direction, to make the upper roller L wind up or draw the cloth, whilst the lower roller unwinds and gives out the cloth. N is a pipe, which conveys water to the machine; it is pierced with a number of holes to throw jets of water on the cloth, and wet it.

As fast as the cloth is taken up by the roller L, it is given out by the other roller J, and is then drawn over the surface of the cylinder, as at G, the teasels of which, as it revolves, act very effectually on the cloth to raise the nap. When the whole piece has passed, and is gathered up on the roller L, the machine is stopped, by shifting the strap 2 to the loose pulley D, then the two rollers L and J are exchanged, and the operation is repeated as before, and so on till the nap is sufficiently raised.

The mode of repeating the action on the cloth by exchanging the rollers is troublesome, and a better mode is to provide the means of disengaging either of the wheels K or I from its respective pinion, making the machine so that only one wheel and pinion can be engaged at once; also to make the motions in such direction that the roller which is engaged shall always wind up the cloth upon itself. Each roller must have a small wheel upon one end of it, as shewn at 10, with a lever and weight 11, to press upon the circumference of the wheel with such force as to occasion a friction, and make the cloth draw tight when it is drawn off the roller. In this way, the cloth can be made to work either backwards or forwards; because that roller which is engaged with the wheel-work will wind up the cloth, and draw it off from the other roller across the drum; but when all the cloth is wound off, that roller which has taken the cloth must be disengaged, and the other put in action, which will make the cloth work back again.

The most improved gig-mills used in Yorkshire have a still better method of moving the cloth. This is by means of a pair of rollers in the place of the upper roller L: they are turned round by a large spur-wheel on the end of the roller, which works in a smaller wheel on the end of the drum; one roller is mounted over the other, like the two rollers of a flattening-mill, and pressed together by screws with sufficient force to draw the cloth between them. The piece of cloth, when brought to the machine, is laid down on a board on the ground before the machine, and one end is passed under the roller J, which is merely to guide it; then it is carried over the drum, as at G, and introduced between the pair of rollers at L, which draw it slowly forwards; from these the cloth turns upwards, and is extended horizontally over two rollers which are suspended from the ceiling. After quitting these rollers, it descends perpendicularly, and is gathered on the ground in folds on a board or bench, close to the place where the piece of cloth was laid before the dressing was begun. In order to make the piece of cloth pass a second time through the machine, or as many times as is required, the two ends of it are sewed together, so that it circulates continually over the drum without any interruption or trouble: it is usually done three or four times.

It is an advantage of this method, that the cloth, in descending from the ceiling, hangs perpendicularly, and with that side which has been dressed opposite to the light, so that the workman who gathers it in folds can examine the progress of the work; and when he judges that the cloth is sufficiently dressed, he cuts the sewing which unites the two ends together, and then the end of the piece comes out of the machine, and the cloth is carried away to give place to another piece.

The drum or cylinder of the gig-mill is composed of a number of shallow troughs, fixed on the circumference of the wheels of the drum, and parallel to its axis: into these troughs, frames filled with teasels, like those we have before described, are fastened in a very simple manner; and the frames are placed so close together, that the trough is wholly filled, and forms a continuous surface of teasels to act upon the cloth when the cylinder revolves. When the hooks of the teasels become filled with flocks or fibres of wool, which they have drawn out from the cloth, they are removed from the cylinder, in order to be cleaned by children, who pick out the flocks with a small steel comb.

The teasels are cultivated very largely in the clothing countries; but it sometimes happens, in particular seasons, that the crops fail, and they are then very dear. This has produced many trials of metallic teeth as substitutes for teasels. Mr. Price of Stroud, in Gloucestershire, has two patents, dated 1807 and 1817, for this object; Mr. Laffalle of Bristol took a patent in 1816, Mr. Williams of Fursley in 1817, and Messrs. Lewis of Brimscomb in 1817. We are not informed if any of these inventions are yet brought into real use in the manufacturing district.

Shearing or Cropping the Cloth.—By the operation of the teasels, the wool is become raised all over the surface of the cloth in a loose fur, which must be removed by shearing before the cloth will be fit for wearing, because the fur would gather dirt and dust, and would wear very unequally.

The shears used for cropping by hand are the same as those used in the common shearing-machine, and are represented at E, E, in *Plate III. Woollen Manufacture*. The clothier's shears consist of two very large flat blades of steel, united together by a stem of steel, which is bent into a circular bow, and is sufficiently flexible to allow one of the blades to be moved upon the other, in order to make them cut. Both blades are ground to sharp and straight edges, which apply one to the other, but the blades are not in parallel planes like scissars, for one of the blades is laid quite flat upon the cloth, and the plane of the other blade will then be inclined to the cloth at about an angle of 45 degrees, as is shewn in *Plate III*. The cutting-edge of this inclined blade bears upon the surface of the flat blade, and the spring of the bow is so set, as to press the two edges always in contact. The lines of the edges of the two blades are not parallel to each other, but inclined, so that the edge of the upper blade crosses the edge of the lower blade, and bears upon the flat surface of that blade, at the end nearest to the bow, whilst the other end of the edge of the upper blade is removed over the edge of the lower blade, thus leaving an interval between the two edges, when the shears are open, as is plainly shewn in the figure. In this state, the shears being open, if the lower blade is laid flat upon the surface of the cloth, the nap or wool, which is to be removed by the cropping, will stand up above the edge of the lower blade, in the interval between the two edges; then if the blades be forced together, the edge of the upper blade will pass or cross over that of the lower, and cut away all the wool which projects above the edge of the lower blade. The contact of the cutting-edges begins at the end nearest to the bow, and proceeds regularly to the other, because, as before mentioned, the edges are not parallel to each other. The blades open or return to their former position by the elasticity of the bow, but in order to make the cut they are closed by means of a handle or lever 10, which is fitted or lodged on a round part of the stem of the bow, so as to play thereupon as upon a centre of motion. A double cord is made fast to the lever or handle near to this centre, and

the other end of the cord is fastened to a block of wood, which is screwed to the flat of the lower blade, and rises up to a proper height. By depressing this handle, the shears are closed, and make their cut with the greatest facility, the elasticity of the bow returning the handle.

The manner of cropping with these shears is as follows :— The piece of cloth is laid down in folds upon a plank or low bench placed on the ground, and the end is drawn across a table or bench, which is covered with cloth, and stuffed with horse-hair, like a cushion. The cloth is stretched out flat upon the surface of the table, and is retained by hooks and weights. Two workmen are employed to shear a piece of cloth; they place the lower blades of their shears flat on the surface of the cloth, with the line of the edge in the direction of the length of the piece; one of the shears is laid on the edge or lift of the cloth, and the other exactly in the middle of the breadth of the cloth. The bows and stems of the shears project over the edge of the table, and the workmen place themselves at that edge. Each man guides the shears with his left-hand, and makes the cut with his right. To hold the shears by, a short staff is lashed to the bow of the shears, and secured by a stay to the lower blade; its direction is nearly parallel to the back edge of the upper blade. The workman puts his arm through the bow as far as the elbow-joint, then lays the fore-arm flat against the staff, which he grasps with the hand; and in this way he has a great command of the shears, leaving the right-hand at liberty to work the handle which closes the shears. This handle is moved backwards and forwards with great rapidity, to make cuts or clips on the cloth, and between every cut the lower blade is moved a small space on the cloth, to cut in a fresh part.

The art of shearing consists in moving the shears with great regularity and parallelism, so that every part of the surface shall be equally cropped. The closeness with which the shears cut is regulated by weights laid upon the flat of the lower blade; these press the blade down into the soft cushion on which the cloth is spread, so that the fur will stand up more above the edge of the blade.

As the two shearers advance in their work, their shears proceed across the breadth of the piece of cloth, and when the man who began in the middle has worked to the lift of the cloth, the other who began at the lift will have worked to the middle, where the first began; the whole breadth is now shorn, and they remove the shears, and draw the piece of cloth forwards across the table, to obtain a fresh surface to work upon.

For shearing common cloth, it is cut wet the first time, then it is dressed again with teasels, dried on the tenter, and cut again in a dry state three times over.

Shearing-Frame.—The most common machine used in Yorkshire is only applied to give motion to the same kind of shears as are used for cropping by hand, and is usually called the shearing-frame. At the side of the table or cushion on which the cloth is spread, a long stool is placed, having grooves at the edges to guide the wheels of a carriage, to which the shears are affixed by their bows. There is a carriage for each pair of shears, and they are slowly and gradually moved along the stool, by a cord which winds upon a roller turned by wheel-work; and at the same time, the handles of the shears are continually pulled by a cord connected with a small crank, which turns round very rapidly. The direction of the cuts is the lengthways of the piece of cloth, and the two pair of shears advance across the breadth of the piece until a whole breadth is cut; the machine is then stopped, the shears removed, and the piece of cloth shifted upon the table. These shearing-frames

operate very well, but require great care and attention to make the different cuttings join, in order to cut equally over the whole surface.

The machine invented by Mr. Harmar of Sheffield was of this description; his first patent was in 1787, and another in 1794. At one period his machines were in general use, but the present shearing-frames, although of the same kind, are very much simplified, and work equally well.

A *perpetual Shearing-Machine* is represented in *Plate III. Woollen Manufacture*; it is used in the west of England, and is best adapted for narrow cloths. The shears lay crosswise over the piece, which is drawn regularly beneath the shears in the direction of its length without any interruptions; hence it is called a perpetual shearing-machine.

The shears, E E, are the same as what we have already described. Each pair is fastened across the frame by means of a piece of wood, to which the lower blade of the shears are screwed; immediately beneath this blade is the cushion to bear the cloth, which passes between the blade and the cushion. The piece of cloth is wound round the roller C, upon the end of which is a wheel N, and a lever M, which bears up against the lower part of this wheel with so much friction as to make the cloth strain tight in drawing off from the roller. The cloth first passes over a rail B, from which it proceeds in an horizontal direction beneath the two pair of shears E E, then turns over another rail at the other end of the frame, and descends to a roller D, which is turned slowly round by the machinery, in order to wind up the cloth.

The machine is put in motion by the endless strap round the drum F upon a shaft, which proceeds all the length of the mill. The strap turns the pulley G upon the end of the small horizontal spindle H: in this spindle two cranks are formed at *a* and *b*, which are connected, by wires 7 and 8, with the handles 9 and 10 of the shears E, so as to give them a continual motion, and make a cut of each pair of shears every time the spindle H makes a turn. The motion of the machine can be stopped by releasing the lever P, on which the bearing of the spindle is screwed: when the lever P is depressed, and kept down by the catch, as represented in the drawing, the endless strap is drawn tight, so as to turn the spindle; but if the catch is removed, and the lever raised up, the strap becomes loose, and slips round upon the pulley without turning it. A small pulley is fixed upon the spindle at I, to receive an endless strap which passes round a larger wheel J. Upon the same axis with this are three other pulleys of different diameters, which receive a strap 2, and give motion to three similar pulleys fixed upon a spindle 3: the latter spindle has a pinion on the end of it, which works a bevelled wheel fixed on the end of the roller D, and thus it is turned slowly round. The three pulleys on the spindles 3 and J are placed reversed to each other, that is, the smallest pulley on one is opposite to the largest on the other; by this means, the same strap 2 may be shifted, and will work on any of the three pair of pulleys, but each one will communicate a different degree of movement to the roller D, and consequently to the cloth, so as to draw it quicker or slower, and make the successive cuts of the shears at a greater or less distance asunder at pleasure.

The cushions which bear up the cloth against the shears are moveable on centres of motion, and are capable of being raised or lowered. When they are lowered down, the cloth can be readily introduced beneath the lower blades of the shears; and when raised up, they press the cloth up to the shears, and the force of this pressure can be regulated by turning a small handle. In many machines this motion is

applied to the shears themselves, instead of to the cushion or bed, and is much more convenient.

The perpetual machines answer very well for shearing narrow cloth, when the shears can cut at once across the whole breadth; and then as the two shears E work in succession over the same surface, they crop the cloth twice over in passing once through the machine. It has been attempted to shear wide cloths in this machine, by making one pair of shears take one half the breadth, and the other pair the other half; but it is very difficult to draw a wide piece of cloth so evenly over the cushions, as to keep it stretched to the full breadth without any wrinkles in the lengthways of the piece; and if there are any such wrinkles, the cloth will be cut very irregularly. In this particular, the first machines have the advantage, because the cloth is stretched over the cushion by the workman with discretion, and he makes it tight before the cropping is begun.

There have been many patents for the improvements of shearing-machines. Mr. Buffington's, in 1804, is for a method of stretching or extending the cloth breadthways whilst it is in the shearing-frame. His plan is to attach a narrow web of strong cloth to the lifts of the cloth, by sewing or lacing; the outer edge of this web is also sewed to a cord or small rope, so that the cloth becomes edged or bordered with ropes. These ropes are conducted through holes or openings in the frame, which will suffer the cloth and ropes to be moved in the direction of their length; but as the ropes cannot draw sideways out of these openings, the cloth may be continually stretched in its breadth. The openings should have rollers to facilitate the motion of the ropes.

Mr. Joseph Fryer's patent shearing-machine, dated 1802, acts with three shearing-blades, one long one, which extends across the breadth of the piece to form the lower or fixed blade, and two other moveable blades of half the length, which are jointed to the long blade at the two ends, and are moveable thereon, so as to cut in the manner of scissor-blades. The moveable blades are pressed into contact with the edge of the fixed blade by springs, and are put in motion by means of two cranks upon an horizontal spindle, so that the blades make their strokes or cuts alternately. The edge of the lower blade is a straight line, but the edges of the moveable blades are convex on the cutting side, so as to cause them to intersect the edge of the lower blade always at the same angle when they are wide open, as when they are nearly closed.

The piece of cloth is conducted over proper rollers, and wound up by one, which is turned round by the machine, so as to draw the piece of cloth from one end to the other with a slow and progressive motion. The cloth, when it is immediately beneath the edge of the long blade, is bent suddenly over a narrow ridge of metal, which is parallel with the edge of the lower blade, but so far distant as to permit the cloth to pass between them. This ridge of metal is capable of adjustment by means of screws, and can be placed so that the nap of the cloth will be shorn longer or shorter, as it is required.

In some cases, especially in finishing broad-cloths, instead of drawing the piece from end to end, it may be more convenient to cause it, or part of it, to move under the shearing-blades from lift to lift, or from one side to the other. This will require a machine considerably larger, though the same blades will suffice; or it is found equally convenient to cause the blades, at the time they are cutting, to move over the cloth in any direction, but more especially from lift to lift.

Mr. Fryer also contemplated the finishing of the cloth
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by the same machine which performed the shearing. Thus after the cloth has undergone the operation of shearing or cropping, in its passage down to the cylinder on which it is wound up, it is exposed to a current of steam thrown out from a horizontal tube at a number of small apertures, so as to give softness and pliability to the cloth; a brushing cylinder is next made to move against it, by which the remaining wool or fur is laid in one direction. It then passes between two polished metal cylinders, which are made hollow, and kept hot by the admission of steam or otherwise. These occasion a great pressure on the cloth, and dissipate all the water imbibed from the steam.

Rotatory Shearing-Machine.—A very complete machine for cropping cloth of any breadth was invented by Mr. Price, of Stroud, in Gloucestershire, and for which he obtained a patent in 1815. This machine shears or crops the cloth across the breadth, beginning at one end of the piece, and continuing regularly to the other. For this purpose, the cloth is conducted through the machine by the motion of rollers, and is drawn over a bed or support which lies beneath the stationary or fixed blade of the shears or croppers, (which answers to what is called the ledger-blade in the common shears,) so that the cloth passes between the bed and the stationary blade.

The moving blades of the shears are fixed on the circumference of a cylinder situated above the fixed blade, with its axis exactly parallel thereto, and capable of revolving by the power of machinery, so that the edges of the moving blades will be carried against and passed over the edge of the fixed blade, in order to cut away all the wool of the cloth which rises above the edge of the fixed blade. Several such moving blades are fixed upon the same cylinder, to act in succession against the fixed blade; and these moving blades are placed obliquely to the axis of the cylinder, or in such a manner as to form portions of spirals; but as all parts of the cutting edges are equidistant from the axis of the cylinder, it is manifest, that in the revolution of the cylinder, every part of each spiral edge is brought in succession into contact with the fixed blade, so that in its revolution it crops off all the wool, which by the progressive motion of the cloth over its bed is raised up against the fixed edge. The edges of the moving blades are placed at such a degree of obliquity to the axis of the cylinder, that at the same instant the end of one ceases to cut against the edge of the fixed blade, the following revolving blade will begin its action at the other end of the cylinder; therefore, by the time that any one of the revolving edges has passed over and made its cut against the whole length of the fixed blade, and is ready to quit it, the succeeding revolving edge is brought into action, and when this has passed, the next in succession begins, so as to keep up a continued action.

The cloth is stretched in width by a contrivance which he calls stretching-bands, to prevent it getting into folds or wrinkles, which would be injured by the shears, or make irregularities in the shearing. These stretching-bands are endless straps or bands, each of which is extended over two wheels. The bands have sharp pins projecting from them to prick into the lifts at the edges of the cloth, and the bands being so situated that one of them lies exactly beneath each lift, they will be caused to circulate round their respective wheels by the motion of the cloth. The stretching of the cloth is effected by the position of the wheels on which the bands circulate, the direction of the bands being slightly oblique to the lengthways of the cloth. The endless straps are so fitted into grooves or troughs, that they are firmly retained to move straight forwards in their oblique direction; and the direction of the obliquity is such, that the

bands are nearest together at that end where their pins take hold of the lifts of the cloth; but as the bands move forwards with the cloth, they recede from each other, and extend the cloth in breadth in consequence of their obliquity, which may be increased or diminished as is found necessary. The actual width between the two bands can also be regulated according to the width of the piece of cloth.

It is not usual to crop the lifts of the cloth, and indeed as the lifts are usually of thicker substance than the other parts of the cloth, they would bear up the fixed blade too high from the cloth to cut the nap quite close.

For this reason, the bed or support on which the cloth is cut is so constructed, that it can be adapted in length to the breadth of the piece of cloth between the lifts, in order that the cloth only may be supported or borne up to the edge of the fixed blade; whilst the lifts, being depressed or borne down below the level of the bed, (by thin slips of metal called guards,) will escape the action of cropping, and thereby remain with the long wool upon their surfaces. The bed by which the cloth is borne whilst it is cut is only a narrow ridge of metal, over which it passes, so as to be bent with a sudden curvature, and in this way, the nap can be cut more close and even than upon a flat bed or soft cushion. The operation of cutting is facilitated by a row of pieces of metal screwed to a strong bar, to form a straight edge, very similar to the cutting edge of the fixed blade, but thin and elastic; this edge is placed close to the elevated ridge of the bed, and presses the cloth gently down upon the bed immediately before it comes to the edge of the fixed blade, against which the nap is to be cut off; this elastic edge being placed on one side of the ridge, and the cutting edge of the lower blade on the other side, the cloth is only exposed for a very narrow space just where it comes to the cutting edge. By this means, the cloth can with safety be brought nearer to a level with the upper surface of the fixed blade, so as to shear it closer than could otherwise be done without endangering the cloth.

The ends of the ridge part of the bed are composed of a number of narrow plates of metal, accurately fitted together, and placed side by side in a mortise made in the end of the solid bed; their upper ends project out of the mortise so as to line with the elevated ridge, and form a continuation thereof; but there is a sliding piece in the bottom of the mortise on which they all bear, and the point of it is of a wedge form. By removing this wedge, any number of the moveable pieces may be let down, so as to diminish the length of the elevated part of the bed at pleasure, according to the breadth of the cloth. The whole of this machine is very well contrived to effect the desired object; it will be found fully described with drawings in the *Repertory of Arts*, vol. xxix. p. 65.

Frizing is an operation sometimes used in the finishing of woollen cloth: it consists in rolling up and entangling the fibres, which form the nap on the surface of the cloth into small knots or burs, which cover near the whole surface, so that the cloth appears covered with small grains, which almost touch each other.

This operation is of no utility to the cloth, and it is difficult to say for what reason it was ever practised at all. The French first introduced it, and it was so much the fashion many years ago, that no other cloth was thought comparable in beauty. At present it is but little used, except for foreign markets, where our cloth meets the French cloth, which is still prepared in this manner, but generally on the back-side of the cloth only.

The frizing is done by a simple machine, in which the cloth is drawn across a narrow table by means of rollers,

to give it a very slow progressive motion. The table is covered with a coarse strong cloth, and over the table is placed a heavy plank of wood, of the same size as the table. The lower side of this plank, which bears upon the cloth, is covered with an artificial stone, composed of coarse sand, which is stuck together into a solid mass by glue or other cement, and a small but rapid reciprocating motion is given to the plank by means of two cranks of very small radius. These cranks are formed at the tops of two vertical spindles, the upper ends of which are fitted in sockets at the ends of the fixed table, and the ends which project up a few inches above the surface of the table are received into sockets formed in each end of the moveable plank. The projecting parts of the spindles are not in straight lines with those parts which are fitted in the fixed collars at the ends of the table, but are slightly cranked; hence, if the spindles are turned round, they must communicate motion to the plank, and slide it over the cloth backwards and forwards; or rather they move it with a circular motion, causing every point and grain of sand cemented to the plank to describe a small circle upon the cloth. It is this action which gathers together the fibres of the nap, and entangles them into knots or grains, as before mentioned.

To put the two spindles in motion, each one has a trundle or lantern fixed on the middle part of it, and the lower end is received in a stationary socket. These lanterns are turned round by the teeth of two face-wheels, fixed upon an horizontal axis, which lies beneath the machine. By this means, both the spindles and cranks are turned round at the same time, and with a very rapid motion. The rollers which draw the cloth forwards are turned round slowly by a communication of wheel-work, and draw the piece of cloth through the machine, that is, across the frizing-table, so that every part is in turn subjected to the action of the sand cemented to the plank. The nap must be left long for that cloth which is intended to be frized, and the operation is repeated twice or three times. See some further particulars in our article *FRIZING*, vol. xv.

Brushing.—After being shorn for the last time, the cloth is brushed all over, to remove the loose cuttings. This operation is now commonly performed by a machine which has two horizontal drums, or cylinders, covered with hair-brushes on the circumference. The piece of cloth is conducted over a system of rollers to extend it and draw it slowly forwards: it is conducted over one of the brushing-cylinders, and under the other; and as they are kept in rapid motion by the machine, they brush over both sides of the cloth at the same time, and lay all the fibres one way.

Pressing.—This is the last finish to the cloth, and gives it a smooth and even surface. The piece of cloth is folded backwards and forwards at every yard, so as to form a pack on the board of a screw-press; and between every fold sheets of glazed paper are placed, so that no part of the surfaces of the cloth can come in contact; also at every twenty yards three hot iron plates are put in between the folds, the plates being laid side by side, so that they occupy the whole surface of the folds; and thin iron plates, which are not heated, are also put above and below the hot plates to moderate the heat. When the pack of cloth is properly folded, and the press contains a proper quantity, the screw is forced down to give a very severe pressure to the pack. The cloth remains in the press until the plates are quite cold; it is then taken out and folded again, so that the creases of the former folds will come opposite to the surfaces of the paper, in order to be pressed with other hot plates.

The heat tends to soften the fibres of the wool, and the

pressure against the glazed paper, whilst they are so softened, lays all the fibres flat and smooth, so that the cloth has a very glossy appearance, and feels smooth, like satin; but this high finish to the cloth is very objectionable, because the slightest shower of rain will take it away, and when the drops of rain only wet it in parts, the cloth will become spotted and disfigured. For this reason, in pressing superfine cloth, the plates are very slightly warmed, and the cloth has but little gloss given to it. The glazed paper is a thick kind of cartridge, which is prepared by glazing or rubbing it very forcibly with a flint, as it lies upon a hard metal table. This operation is done by a water-mill.

For coarser cloths, some manufacturers gloss them with a large hot iron: it is a hollow box, into which a red-hot heater is introduced. The cloth is spread out upon a large flat table, and extended by hooks. The iron box is suspended by a tackle from the ceiling, so that it can be hoisted over to the middle of the table, and then two men work it backwards and forwards over the whole surface of the cloth, by means of two long poles or handles, which are joined to it at one end.

The cloth is now finished, and is packed up in bales of twenty or twenty-five pieces, in order to be transported. The bale is first inclosed in paper, and then in canvas, and closely compressed by the screw-presses. Some manufacturers use the hydrostatic presses for this purpose.

In considering the processes of the woollen manufacture, as they were practised forty or fifty years ago, and comparing them with the present practices, we find great changes and improvements, but they are by no means carried to so great an extent as in the cotton manufacture. This is owing in a great degree to the circumstance that the manufacture of woollen cloth was rendered very perfect, as far as the goodness and beauty of the cloth was concerned, long before the improved system was begun; and there were great numbers of experienced and able workmen trained up for each process, who by habit and dexterity performed their work as well as it could be done by machinery. The reduction of labour, or the substitution of ordinary hands for experienced workmen, was in this case all that machinery of the most perfect kind could effect; both these were advantages to the public and the manufacturer, but were so directly opposite to the inclination and interest of the able workmen, that we find they have made greater and more effectual opposition to the introduction of improvements in the woollen than in any other of our great manufactures.

At various periods attempts have been made by the workmen to suppress machinery, and many mills have been destroyed. In July 1802, considerable riots took place in Wiltshire and Somersetshire, in consequence of an attempt to set up the machines called gig-mills. It was contended that this was the same machine which was prohibited by an ancient statute of Edward VI. The disputes ran so high, that the attention of parliament was called to the subject of the laws then existing for the regulation of the woollen manufacture, and a committee was appointed to investigate the policy of encouraging or regulating machinery. In consequence, all the prohibitions of machinery were suspended. The report of this committee contains the following remarks, some of which are applicable to other manufactures as well as the woollen.

The introduction of the gig-mill and other machines was opposed from an idea that it would throw a considerable number of hands out of work; and it was contended, that it was highly injurious to the quality and texture of the cloth. With respect to the actual effects of the gig-mill and shearing-frame on the cloth, the committee report that deci-

five evidence has been adduced before them by merchants and manufacturers of the greatest credit and experience, to prove that these machines, especially the gig-mill, when carefully employed, finish the cloth in the most perfect manner, and that manufacturers residing in parts of the country where the gig-mill is not used, frequently send their cloths to a distance to be dressed by it.

It also appeared in evidence, that alarms similar to the present had existed among workmen at the introduction of several of the machines which are now in general use. Such alarms have gradually subsided as prejudice died away; and the machines are now fully established, without, as it appears, impairing the comforts or lessening the numbers of workmen. The committee remark with much satisfaction, that in many instances in which it was apprehended that the introduction of particular machines would throw such a number of people out of employment as to occasion great distress, the result has been very different; for besides the occupations which the attendance on such machines has given rise to, a fresh demand for labour to an immense extent has arisen out of the increased sale of the article, in consequence of the cheapness and superior quality of the manufacture.

They approve the system of patents, by which the inventor of any new machine secures to himself the exclusive benefits of his discovery for fourteen years; and only, at the end of that term, they are thrown open to the public; this provides in most cases against the too sudden and general establishment of any invention, by which a number of workmen might at once be thrown out of employment.

They next observe, that if the principles on which the use of these particular machines is objected to were once admitted, it would be impossible to define the limits or to foresee the extent of their applications. If the parliament had acted on such principles fifty years ago, the woollen manufacture could never have attained to near its present extent. The rapid and prodigious increase of late years in all the manufactures and commerce of this country is universally known, as well as the effects of that increase on our revenue and national strength. In considering the immediate causes of that augmentation, it appears to the committee, that it is principally to be ascribed, under the favour of Providence, to the general spirit of enterprise and industry among a free and enlightened people, left to the unrestrained exercise of their talents in the employment of a vast capital, pushing to the utmost the principle of the division of labour, calling in all the resources of scientific research and mechanical ingenuity, and, finally, availing themselves of all the benefits to be derived from visiting foreign countries, not only for forming new and confirming old commercial connections, but for obtaining a personal knowledge of the wants, the taste, the habits, the discoveries and improvements, the productions and fabrics, of other civilized nations. Thus bringing home facts and suggestions, perfecting our existing manufactures, and adding new ones to our domestic stock; opening, at the same time, new markets for the product of our manufacturing and commercial industry, and qualifying ourselves for supplying them.

The committee declare it to be their opinion, that by these means alone, and above all by the effect of machinery in improving the quality and cheapening the fabrication of our various articles of export, notwithstanding a continually accumulating weight of taxes, and with all the necessities and comforts of life gradually increasing in price, (the effects of which on the wages of labour could not but be very considerable,) our commerce and manufactures have also been increasing in such a degree as to surpass the most sanguine calculations of the ablest political writers who have specu-

lated on the improvements of a future age. The exports of woollen goods at the time of this report, (1807,) amounted to six millions of pounds official, or nine millions of real value.

It appeared also to be an important consideration, of which we should never lose sight, that we are at this day surrounded by powerful and civilized nations, who are intent on cultivating their manufactures and pushing their commerce; and who are more eager to become our competitors in trade, from having witnessed the astonishing effect of our commercial prosperity. The attempts which have been made to carry our machines and implements over to foreign countries, and to tempt our artisans to settle in those countries, evince the importance of machinery, under the directions of men of approved skill, in constructing and using them. It is needless to remark how much these attempts would be favoured by our throwing any obstructions in the way of enterprise and ingenuity, and the free application of capital in this country; for any machines which should be prohibited here would infallibly find their way into foreign nations in a very short time.

Among the attempts to improve the woollen manufacture, we must not omit to notice the invention of Mr. Joseph Booth, for fabricating woollen cloth without spinning or weaving. This was effected by felting wool into a web by the aid of machinery, which operated mechanically upon a tissue of carded wool, to entangle and interlace the fabrics together. The inventor took a patent for this in 1793 or 1794, but before the time for the enrolment of the specification of his process, he obtained an act of parliament, the

preamble of which states, that on account of the great importance of the art, and the danger of its being carried abroad to the injury of the staple manufacture of the kingdom, parliament had determined to keep the specification sealed; hence we are not able to give the details of this machinery.

We find these expectations have not been realized; for, although the process has been repeatedly tried on a large scale and in the most complete manner, it has been abandoned. Three large mills were established at Taunton and near Salisbury, by experienced woollen manufacturers of the west of England; another mill was converted to the purpose at Lewisham, in Kent; and the last mill was erected at Merton, in Surrey, the property of James Perry, esq. We learn from this gentleman, that he was able to manufacture cloth of a fine surface, and of a very even and regular substance, but it was rather deficient in strength, for want of the threads which form the substance of common cloth; and in respect to wear it was less durable than common cloth, as it did not long withstand brushing; otherwise the expence of the process, which was not one-fourth of the common process, would have brought it into general wear.

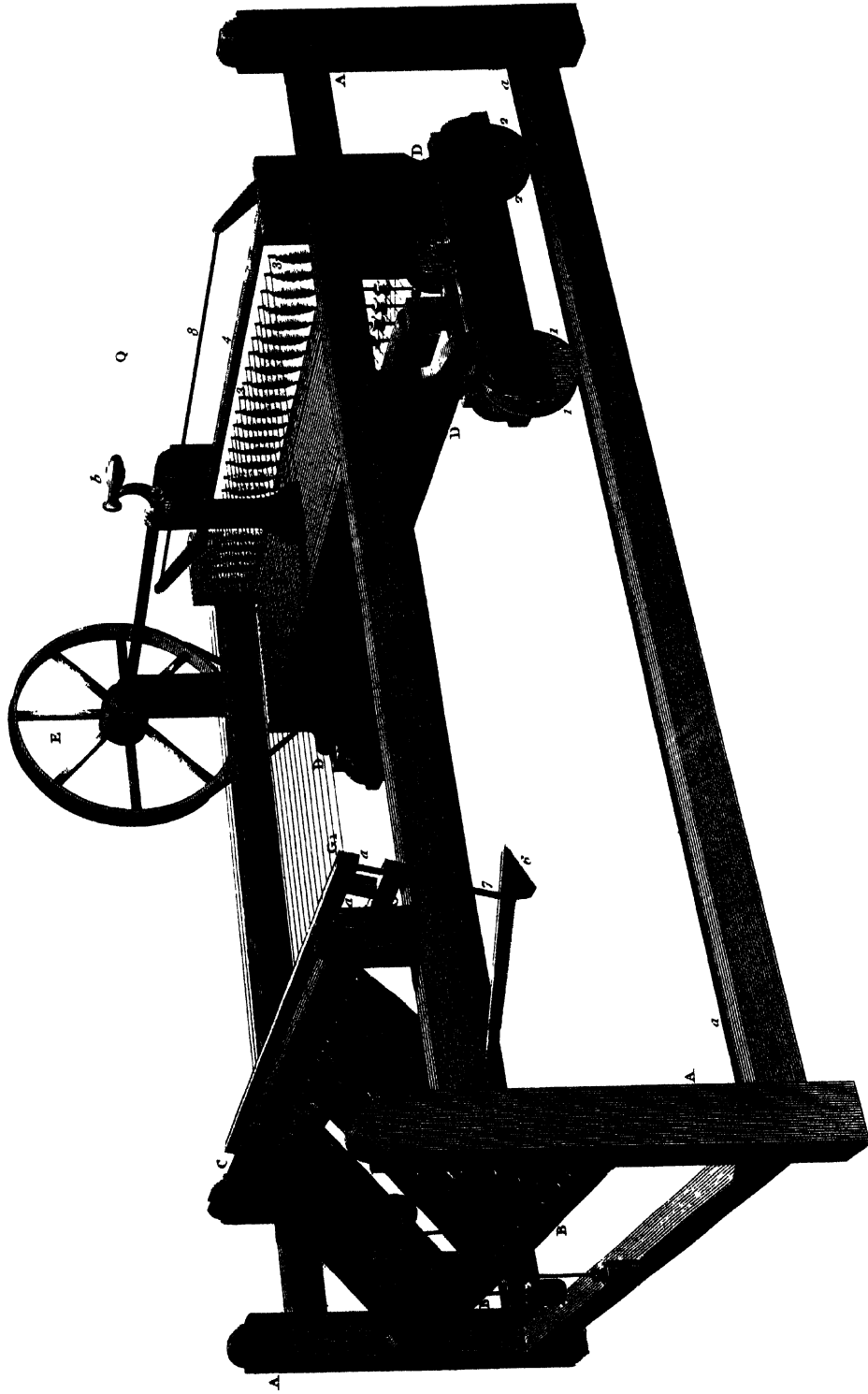
There has been a great number of other projects and patents for the improvement of different branches of the woollen manufacture; but as we have already noticed most of those which have come into use, we shall not enumerate any more of the unsuccessful attempts.

The machinery for manufacturing long combing-wool is described in the article WORSTED.

WOOLLEN MANUFACTURE .

SLUBBING MACHINE OR BILLY .

PLATE I.



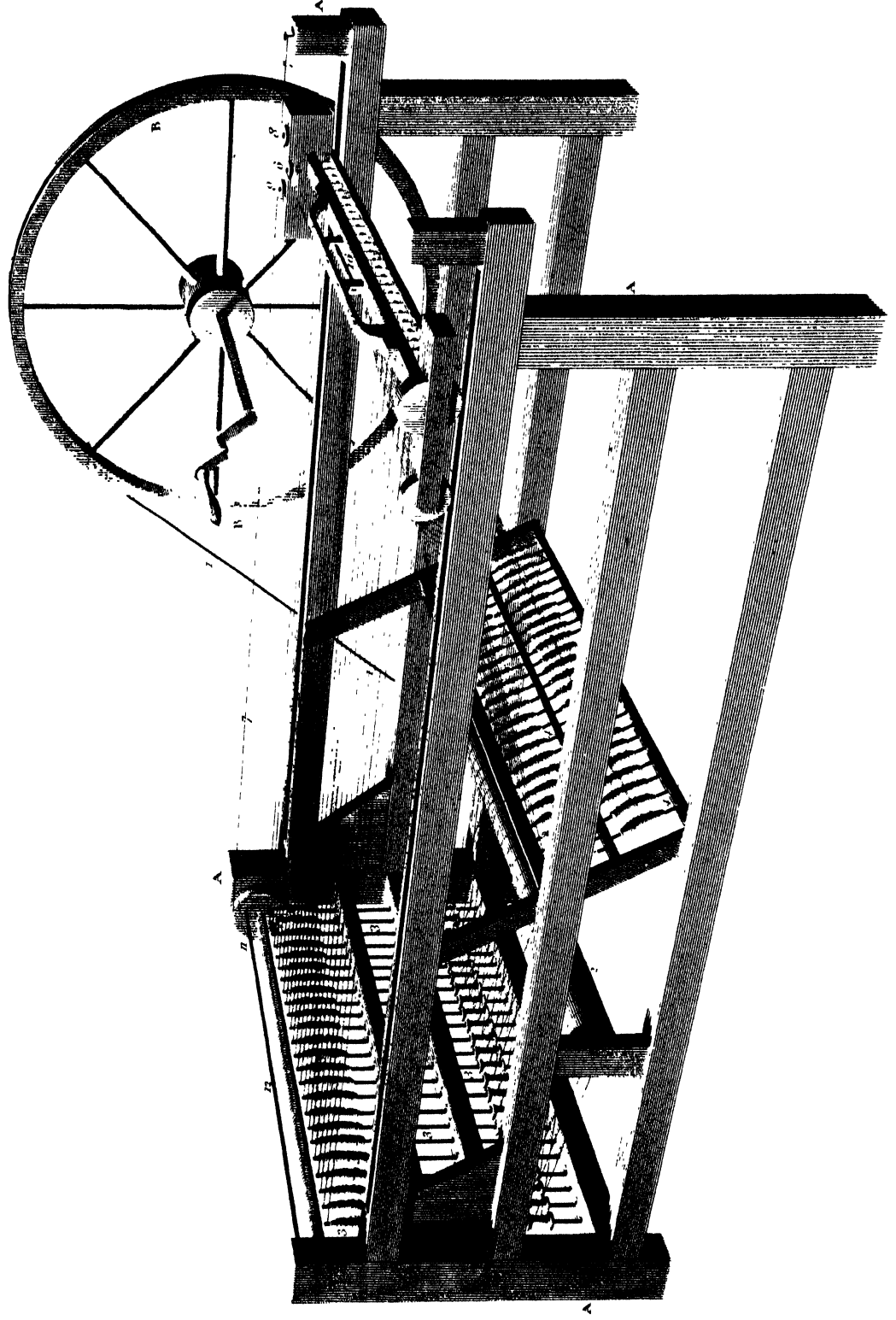
J. Herbert delin.

Published as the property of Messrs. J. & W. Langman, Thurst, near A. Thurst, Paternoster Row.

Engraved by Wilson Lowry

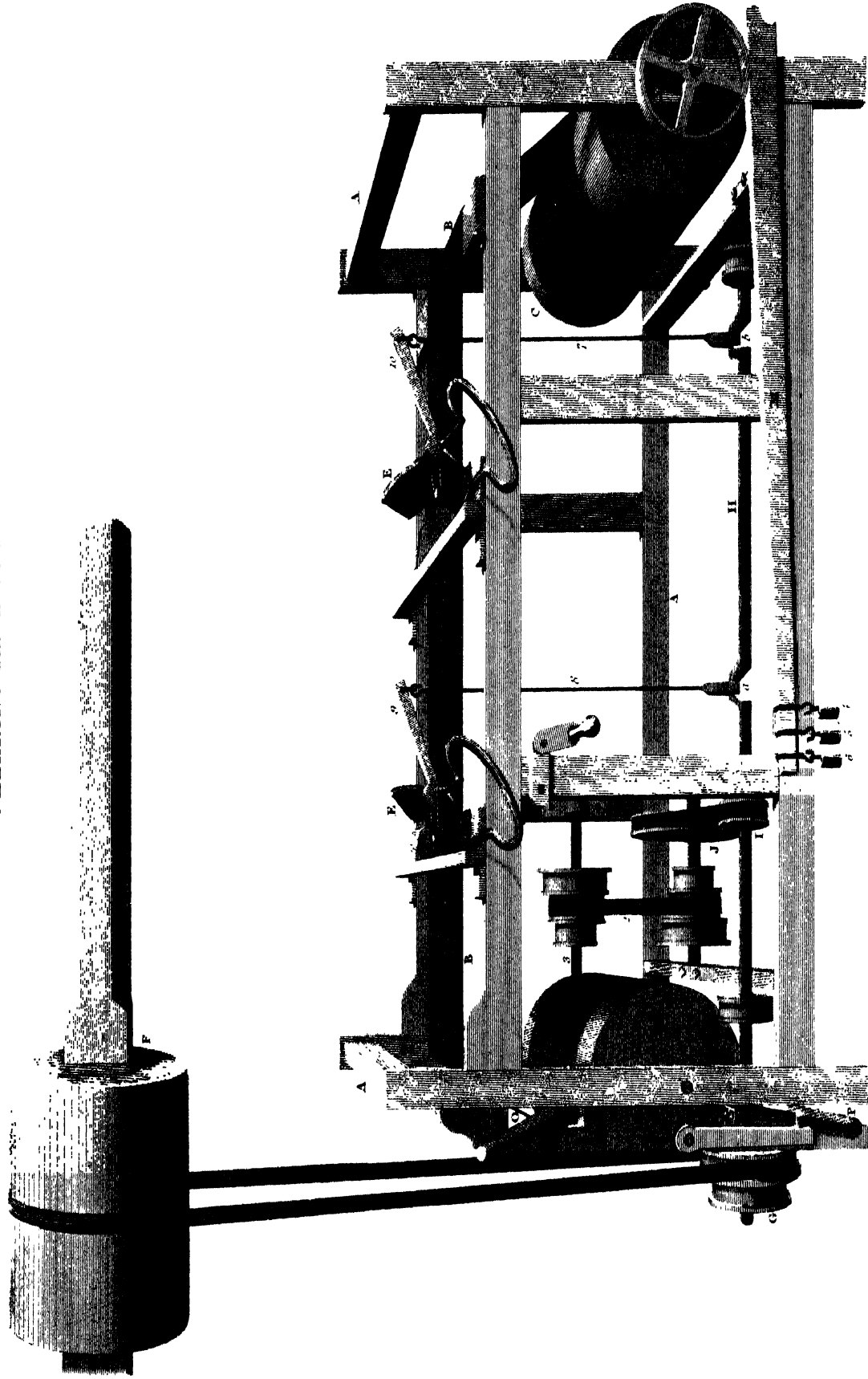
COLLEEN MANUFACTURE

SPINNING JENNY.



WOOLLEN MANUFACTURE. SHEARING MACHINE.

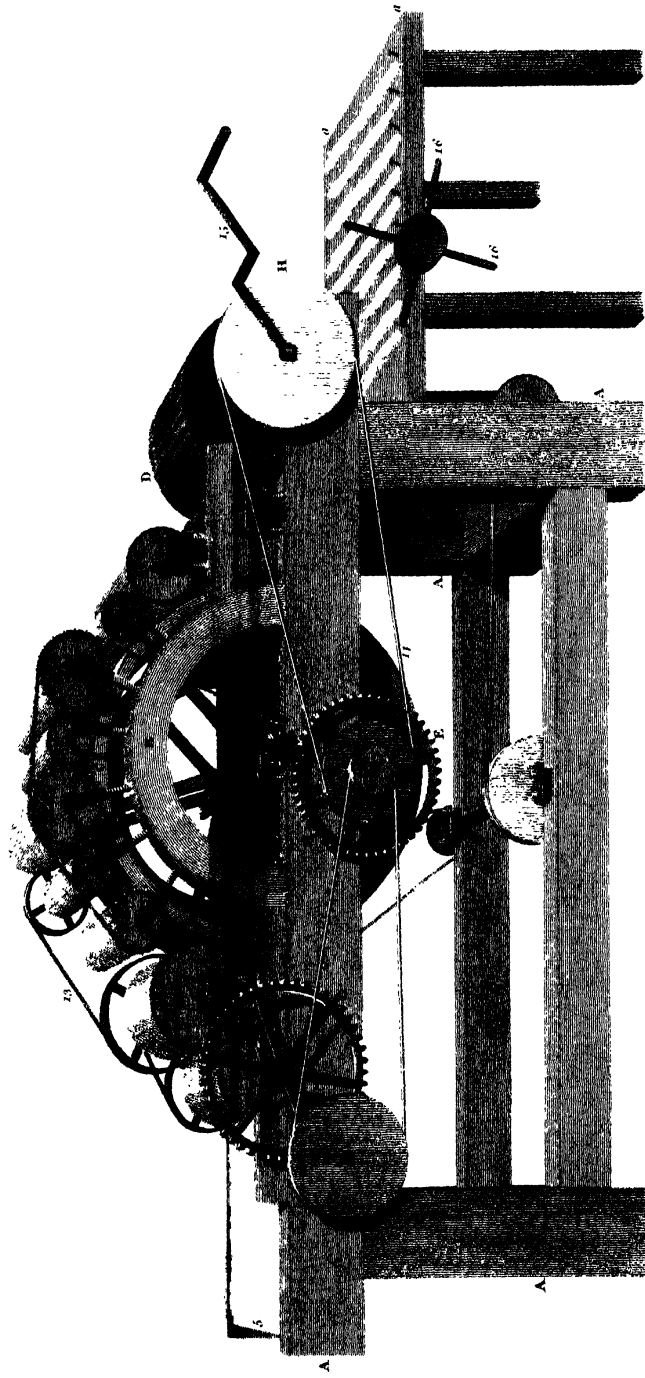
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Published in the September 1871 in London at Messrs. R. & B. Brown, Littlewood Street, Row

WOOLLEN MANUFACTURE. CARDING ENGINE.

PLATE

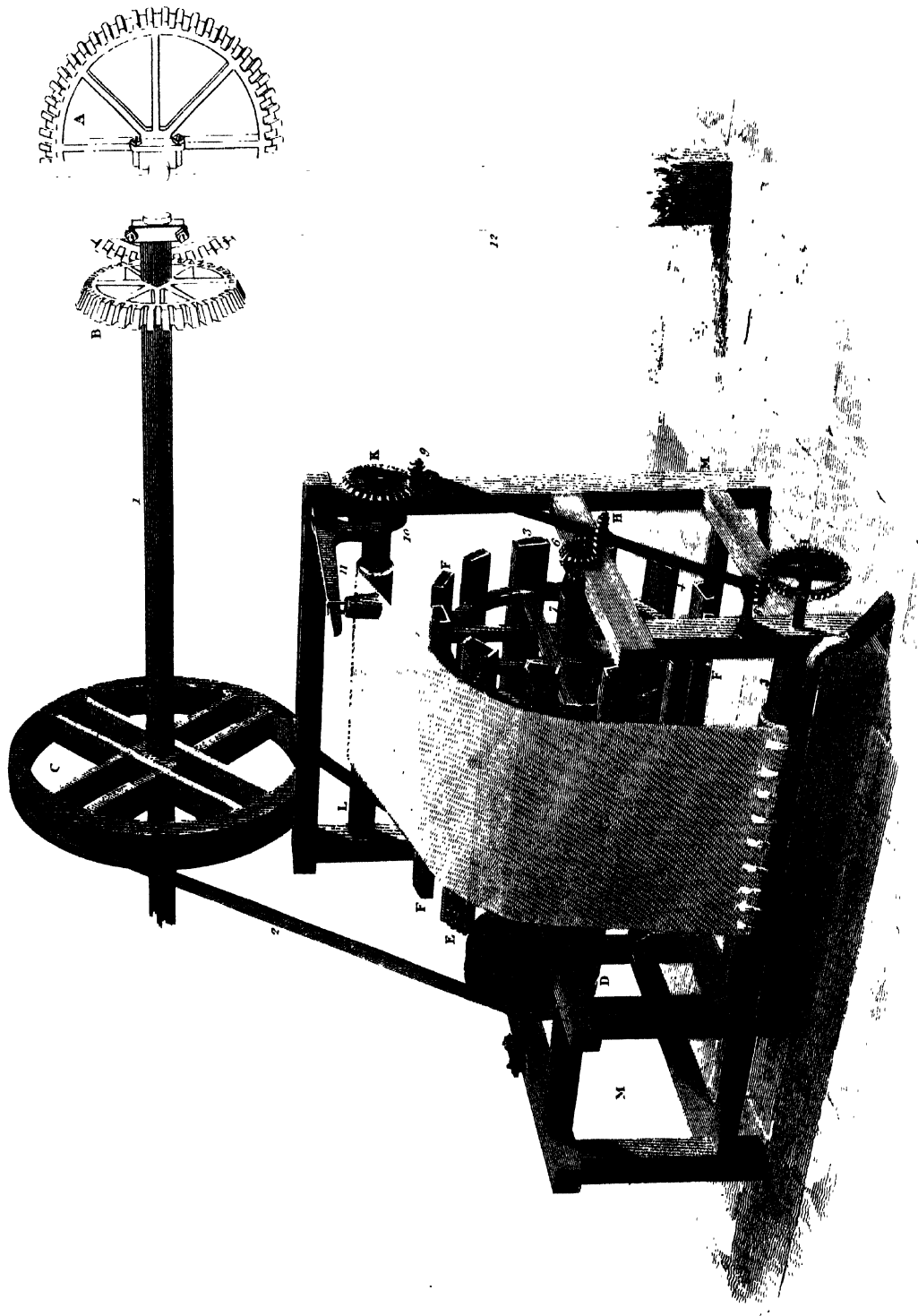


J. D. Herbert delin.

Published as the Art Director, 1899, by L. Ogden, Haver, Ross & Davis, Paternoster Row.

Engraved by Wilson Lowry.

WOOLLEN MANUFACTURE



Worsted

WORSTED, and WORSTED Manufacture. The term worsted is applied to yarn, and manufactured goods made of combed wool. Worsted is properly a branch of the *Woollen Manufacture*, to which article we refer our readers; but the latter term, strictly speaking, is applied only to yarn, or pieces made entirely or in part of carded wool. The characteristic distinction between combing-wool and short or clothing-wool has been already stated under the article **WOOL**. (See **WOOL** and **WOOLLEN Manufacture**.) Worsted goods were made in England as early as the time of Edward II. In the account of exports in the following reign, already given in the article **WOOLLEN Manufacture**, the number of pieces of worsted goods exported is nearly double that of woollen cloths. According to Camden, the name is derived from Worsted, a town in Norfolk, where worsted stuffs were first made. According to Dr. Parry, in his "Essay on the Merino Breed of Sheep," worsteds were called by the Flemings '*Ostades*,' and as the manufacture was in their hands long before it was introduced into England, it is probable that our appellation is a corruption of their's. Ostade was long ago a common surname

in Flanders, and was perhaps that of some person famous for this particular branch of the woollen trade, which afterwards was appropriated to an establishment of similar manufacturers in Norfolk.

Worsted yarn is made of long or combing-wool, in which the fibres are all laid even parallel with each other by the wool-comb. It may be classed into two great divisions, the soft and the hard worsted yarn. The soft yarn is made of the shorter kinds of combing-wool, the sorting of which has been already described under the article **WOOL**. The short and long combing-wools are both prepared for spinning by the comb in the same manner, except that for some kinds of fine hard yarn made from the latter, the wool is combed, and afterwards spun nearly without oil. This is the case with the yarn for bombazines. The soft yarn for hosiery receives but little twist in the spinning, and two, three, or more threads are afterwards twined together on what is called a doubling-mill, to make a thread of requisite strength and thickness to be woven on the stocking-frame. See **STOCKING-Frame**.

Knitting-yarn is twined much harder than yarn for the frame. For mixed coloured stockings, part of the wool is dyed and mixed with the white in the process of combing. The principal seats of the worsted hosiery manufacture in England were Nottingham and Leicester; but of late years the worsted hosiery has declined at the former place, the trade there being principally confined to silk and cotton articles. Formerly hosiery comprised a variety of worsted articles, particularly caps, which were generally worn in England before the introduction of hats.

At Aberdeen, in Scotland, there is a considerable manufacture of hosiery, the wool being principally supplied from London. Worsted stockings, and lamb's-wool hosiery, to the amount of from fifty to seventy thousand pounds, are said to have been annually exported from Aberdeen to Holland. Of the number of hands employed in worsted hosiery in England, or the annual value of the goods made, we have no correct account. Perhaps some estimate may be formed from the amount of exports of woollen hosiery given under the head *Woollen Manufacture*, in the table of exports, in which it will be seen, that in the year 1816 the worsted hosiery exported amounted to one hundred and fifty-one thousand and sixty pounds. This, we believe, includes the hosiery made of woollen yarn, or what is generally called lamb's-wool yarn, an article which, since the beginning of the present century, has been greatly increasing in demand. Soft worsted yarn for hosiery, during the last twenty years, has been principally spun and doubled by machines in large worsted-mills. Previously to that time, worsted-making by hand-spinning was a distinct trade from hosiery. The worsted-maker bought his different sorts of combing-wool from the wool-stapler, combed and spun it, and sold the yarn to the hosier. Since then, the hosiers have been principally supplied with worsted yarn from large mills established in Leicestershire, Nottinghamshire, and Warwickshire. Of late, however, many of the hosiers are manufacturing their own yarn on machines or mules turned by the hand, or in small mills turned by horses or water.

The combing-wools of Kent are better suited for hosiery worsted yarn than any other in England, particularly for machine-spinning. This excellence is derived partly from the softness as well as soundness of the wool; but particularly from the staple being nearly of one uniform thickness from the bottom to the top. See *WOOL*.

Picardy and Normandy were the principal seats of the worsted hosiery in France. Under the article *WOOLLEN Manufacture*, it will be seen that 1,250,000 pounds weight of wool were consumed annually in the manufacture of hosiery in Picardy before the French revolution.

The stocking-frame was invented by William Lee, M.A. of Cambridge, in 1589, and was afterwards introduced into France. This invention took place in England only 28 years after the knitting of hosiery yarn on needles had been introduced from Spain. See *STOCKING-FRAME*.

Hard worsted yarn for worsted stuffs or pieces is spun much smaller, and twined much harder, than the soft worsted yarn for hosiery. In all the stouter kinds of worsted goods, the long or heavy combing-wool is used. (See *WOOL*.) Under the article *WOOLLEN Manufacture* we have noticed the introduction of the worsted trade into England, and various places where it was first established. Norwich and some of the towns in Norfolk and Suffolk appear to have been the first where any considerable quantity of worsted pieces or stuffs were made. The names which the different kinds of worsted pieces have received are very numerous, being often derived from the manufacturer who introduced a slight change either in the mode of weaving or

finishing the goods. These names soon became obsolete, being supplanted by other kinds of worsted goods, so that we do not know at present to what particular kind of pieces some of them were formerly applied; the essential difference consisting in their being woven plain, twilled, or figured, or made with a warp of single or doubled yarn, and woven stouter or more slightly, or of greater or less width, and whether they were glazed or not in the finishing.

The most important distinction between worsted pieces and woollen cloth consists in the former not being milled or raised, so as to cover the surface with a pile, but the thread is left bare. To take off the loose hairs which rise from the surface, the worsted pieces are passed over a red-hot cylinder, in the same manner as many kinds of cotton (see *COTTON Manufacture*): this process is called *finishing*. For some particular purposes, a slight degree of milling has recently been attempted to be given to worsted pieces in the fulling-mill. The glazing communicated to some kinds of worsted goods is given by pressing them between sheets of stiff glazed press-paper and heated iron plates, which are compressed in a strong pressing-frame. For the weaving of figured pieces, see *WEAVING*, and *DRAUGHT of Looms*.

Some kinds of very fine worsted goods are made with a warp of mohair or silk, as silk camlets and bombazines. The latter goods, with a silk warp and worsted with hard worsted yarn of the finest kind, are manufactured at Norwich. The term bombazine appears to be derived from bombycina, a kind of silk dress used by the Romans, and said to come from Assyria. It is generally understood to have been made from the threads of an insect called the bombyx. Bombycina is sometimes confounded by commentators with byssinum and sericum. Byssinum appears to have been a very fine kind of linen or lace; sericum unquestionably means filken stuff, so called from the Seres, the nation whence it was procured. Probably bombycina was a coarser kind of silk. In the middle ages, the word bombycina was applied to cotton. Macpherson's *Annals of Commerce*. See *BYSSUS*.

Bombazines are woven with a twill, and have, as before stated, a warp of silk and a weft of fine worsted yarn. The Dutch refugees, who fled from the persecution of the duke of Alva, introduced the manufacture of this article into Norwich in the year 1675, when the Dutch elders, according to Blomefield, presented bombazines in court at Norwich. (Blomefield's *Hist. of Norfolk*, vol. ii. p. 205.) Worsted goods were made in Norwich as early as the reign of Edward II. This appears from a patent granted to John Peacock, for the measuring every piece of worsted made in the city of Norwich or county of Norfolk. Norwich has continued from that time one of the principal seats of the worsted and stuff trade. The sale of stuffs made in Norwich only, in the reign of Henry VIII., amounted to 100,000*l.* annually, besides worsted stockings, which were computed at 60,000*l.*

Norwich is at this day the only part of England where any considerable number of the very finest stuffs and bombazines are made. The manufacture of the coarser kinds of worsteds, except camlets, has been transferred in a great measure into Yorkshire. The period preceding the American revolution, from the year 1743 to 1763, may perhaps be regarded as the most flourishing era of the worsted manufactures of Norwich. According to the account of Arthur Young in 1771, the manufactures of this place had increased four-fold in the preceding 70 years. The number of looms was then estimated at 12,000, and each loom was supposed to employ six persons in preparing and finishing

the material; and the total annual value of the goods was estimated at above 1,200,000*l*. Of these goods the estimate then was,

	£
The export to Rotterdam - -	480,000
to London - -	550,000
to various places - -	200,000
Total value -	1,230,000

The number of persons employed being from seventy to eighty thousand.

Since the time to which Arthur Young refers, the manufacturers of Norwich have engaged extensively in the trade of silk shawls and other articles, in which no worsted whatever is used. Still, however, the worsted manufactures of Norwich may be considered as in a flourishing state. The number of looms employed in worsted at the present time (1818) may be estimated at 10,000; half of which weave camlets, calimancoes, and other stuffs; and the other half bombazines, narrow and broad. The former are chiefly for home consumption, the latter for the Spanish market. The East India company take a considerable quantity of the fine camlets manufactured at Norwich.

By far the greatest part of the worsted yarn employed at Norwich is supplied by machine-spinning, from the worsted-mills in Yorkshire, Lancashire, and Durham. But some yarn still continues to be spun in the old manner, by the running-wheel, in Suffolk, Essex, Hertfordshire, and Cambridgeshire. In Norfolk alone, the use of the distaff still remains. This instrument is the most ancient of which we have any notice, either in sacred history, or the fabulous traditions of Grecian mythology handed down to us by Homer and Hesiod. It is at present vulgarly called the rock. In using it, the thread is drawn out from the end of the fliver of combed wool. The motion is communicated to a rough kind of spindle, by twirling it between the right-hand and the thigh, which is suffered to continue revolving when suspended by the thread, which the spinstrefs gradually lengthens with her fingers.

In wheel-spinning, a small portion of the combed wool or fliver is laid across the finger, from the centre of which, called the twitch, the thread is drawn out. About thirty years since, the counties of Norfolk, Suffolk, Hertfordshire, and Essex, not only supplied all the yarn that was wanting for the manufactures of those districts, but sent large quantities of worsted yarn to Halifax and Manchester. At present the trade is completely turned, and, as we have before stated, the greater part of the yarn used at Norwich is sent there from the northern counties of England. This change has occasioned great distress in the villages where the yarn was formerly spun, by depriving the wives and children of the cottagers of their common employment.

Until the middle of the last century, worsted goods were manufactured in considerable quantities in Warwickshire, Oxfordshire, and Northamptonshire; but about that time the extension of the worsted trade in the West Riding of Yorkshire, particularly at Halifax, Bradford, and Wakefield, gradually drew this trade in a great measure away from those counties. The manufacturers in Yorkshire, or rather the merchants who bought the worsted pieces from the manufacturers, were, however, long unacquainted with the best modes of dyeing and dressing them; they were therefore sent to London or Coventry to be finished, but afterwards they were finished in Yorkshire. The demand to Spain, Portugal, Italy, and the Levant, took off the greater part of the worsted goods manufactured at Halifax;

those manufactured round Wakefield and Bradford, consisting chiefly of tammies and shalloons, were consumed principally by England and her colonies. The Piece-hall at Halifax was first opened about the year 1780; and the intervening time, from thence to the year 1792, or the breaking out of the French war, may be regarded as the most flourishing era of the worsted trade in Yorkshire. Though the cheapness of calicoes, as an article of female dress, since the improvements in the cotton manufacture, materially abridged the sale for some kinds of worsted goods in England, this was more than compensated by the increased demand for carpets with worsted warps, and other articles of luxury, in which worsted yarn was employed.

The demand in foreign markets, from the year 1782 to 1792, for English worsted goods, greatly exceeded that of any former period; but after the breaking out of the French war, the worsted trade at Halifax began to decline. The greater part of the foreign markets being closed against us, most of the mercantile houses engaged in the export of worsted pieces were in consequence ruined or declined; the trade altogether, and many of the small manufacturers, engaging in the cotton trade. The introduction of English calicoes into Turkey and other parts tended also to lessen the regular demand for shalloons and other worsted goods, as articles of female dress, in those countries. Soon after the breaking out of the French war in 1792, the spinning of worsted by machinery was established at Bradford and the vicinity; and continuing to increase, drew round that place the manufacturers of worsted goods on the decline of the Halifax trade. Bradford is now become the principal seat of the worsted manufacture in Yorkshire; and some of the proprietors of the worsted mills, besides supplying the smaller manufacturers with yarn, employ a very great number of looms themselves, and carry on this branch of trade on a scale of extent never before known in the worsted manufacture. Within the last two years, the worsted trade has also greatly revived at Halifax.

The following are the kinds of worsted pieces at present principally made in Yorkshire.

Bombazets are woven both plain and twilled, with the warp of single thread; they were pressed, and finished without glazing: the width 22 inches, length 29 yards.

Tammies, or *durants*, with single warps twilled, and generally coarser than twilled bombazets: width from 32 to 36 inches, length 29 yards.

Shalloons are woven with a twill, and have a warp of single thread. We believe the name was derived from Châlons in France. The pieces are from 32 to 36 inches wide, and 29 yards long.

Cubicas are very fine shalloons so called.

Sayes, or *anascottes*, are twilled and made with single warps; they are of two kinds, one running 27 inches wide and 30 yards in length, the other 42 inches in width and 44 yards in length.

Morcens are woven plain and watered or embossed, and are made very stout, being principally used for furniture: their width is 28 inches, length 24 yards.

Calimancoes are woven plain and striped: width 17 inches, length 29 yards.

Camlets are both plain and twilled: width 18 inches, length 29 yards. They are shorter than bombazets, but not many are made in Yorkshire with doubled warps.

Lastings have doubled warps, sometimes of two and sometimes of three threads, and are made with great variety of patterns, either plain, twilled, or flowered, and are distinguished by different names, according to their figures and

quality; as prunelle, amens, (probably from Amiens in France, where they were manufactured,) and drawboys: the width 18 inches, length 30 yards.

Worsted flag, or velvet woven like corduroi and cut, is made principally at Banbury, in Oxfordshire, and at Coventry; but has been manufactured also in Yorkshire.

In the worsted manufactures of France, there were greater varieties of pieces than in England. One kind of camlet, made with a fine warp from the wool of the Angora goat and a weft of fine worsted, was remarkably beautiful; but we believe it has not been manufactured in Yorkshire or at Norwich.

For some account of the worsted manufactures of France, see *WOOLLEN Manufacture*; under which article we have given the history of the worsted manufacture as connected with the woollen, and where may be seen the number and value of the worsted pieces exported from England in the year ending January 1817. See also *long combing-wool*, under the article *WOOL*.

WORSTED Spinning. In the article *WOOL* we have given an account of the different kinds of long wool which are proper for spinning into worsted, also the manner of sorting and scouring them. This wool must be prepared for spinning by repeated combings, with a comb or heckle that is provided with a great number of long steel pins which are sharp-pointed. These points being few in number compared with the teeth of cards, they can be safely introduced between and drawn through the long fibres of the wool, in order to separate and straighten them, without materially breaking them. Another object of the combing is, to separate the short fibres which are intermixed with the long ones; for in spinning any kind of thread, it is desirable that the fibres should be all as nearly as possible of a length.

Wool-combing.—In the ordinary process of wool-combing by hand, the implements used are, 1. Two combs for each workman. 2. A post, to which either of the combs can be fixed, to support them during the operation. 3. A comb-pot, which is a small stove to heat the teeth of the combs, which is found to facilitate the combing. The combs are shewn at *fig. 1. Plate I. Woollen Manufacture*: each comb is composed of two rows of pointed steel teeth, *a* and *b*, disposed in two parallel planes. One of the rows contains longer teeth than the other. They are fixed into a wooden stock or head *c*, which is covered with horn, and has a handle *d* fixed into it, perpendicular to the planes of the rows of teeth. The rows of teeth are about seven inches long, and each row contains about twenty-four teeth. The length of the longest teeth is near twelve inches, and the shorter ones about eight inches. The teeth are made of steel, of a round figure, and regularly tapering from the base, where they are fixed into the stock, to the point, which is quite sharp. The teeth are about one-sixth of an inch in diameter at the base; and the interval between the two adjacent teeth at the base is rather less than their diameter, or one-eighth of an inch. The space between the two planes in which the teeth are disposed is about one-third of an inch at the bases of the teeth. The teeth should be straight and well-tempered, and polished. If they become crooked in working, the workman must straighten them, and set them all in a true line. The combs used for the last combing of the wool have three rows of teeth.

In the wool-comber's shop a post is fixed, as shewn by *fig. 2*, in order to support the combs occasionally during the working. An iron stem *g* is fixed fast into the post, and projects horizontally from it; the extreme end of it turns upwards with a point, which is inserted into a hole through the middle of the handle of the

comb. Also at the other end of the stem *g*, close to the post, there is a small hook *b* rivetted, which terminates with a pointed pin, situated in an horizontal direction. This point is inserted into a hole made in the end of the handle of the comb, in the direction of its length. The end of the comb-handle being first placed on the point of the hook *b*, it is let down upon the other point *g*, which, by passing through the handle, fixes the comb quite fast to the post, as shewn at *fig. 2*.

In the operation of combing wool, it is necessary to heat the teeth of the combs, in order to soften and relax the fibres of the wool, and render them more easy to work. The heat also tends to distribute the oil with which the wool is lubricated. The combs are heated in a comb-pot or stove, *fig. 3*, which is a small furnace built in brick, to inclose a fire-place, of which *A* is the door, *B* the ash-pit, and *C* the flue. Above the fire a circular cast-iron plate *aa* is placed. This is made flat, except in the central part, where there is a concavity, to obtain a better action of the fire. Immediately over the plate *a*, another plate, *bb*, is placed parallel to the former, but with a sufficient space between them to admit the teeth of the combs: several pieces of iron are placed between the two plates, to keep them at a proper distance asunder, and to divide the space into small cells proper for the combs.

In using this stove, the workman must be careful not to heat it too much, and a damper in the flue is very useful to regulate the draught; if the heat is too great, it spoils the temper of the comb-teeth, and injures the wool also. The most improved stove is heated by steam, which will give a sufficient warmth, but cannot overheat the combs.

In order to comb the wool, it is separated into handfuls, each containing near four ounces of wool, which is about a proper quantity to be combed at once. These handfuls are sprinkled with oil, and the wool is rolled in the hands to distribute it equally. The quantity of oil varies from $\frac{1}{4}$ th to $\frac{1}{2}$ th of the quantity of wool by weight. The comb is first heated by introducing the teeth into the stove, in one of the cells between the two iron plates; when it has acquired sufficient heat it is withdrawn, and another comb is put in its place. The heated comb is then fastened to the post, with its teeth pointing upwards, in order to be filled with wool; the comb takes one-half of the handful of wool in his hand, and catches it upon the teeth of the comb by throwing the wool over the points, so that they penetrate it; then by drawing the wool towards him, and at the same time downwards to the bottom of the teeth, a portion of the wool will remain in the teeth. The lock of wool is again cast upon the teeth, and drawn through them, and every time some wool remains; this is repeated as often as is necessary, until all the wool is gathered upon the teeth. The comb thus filled is placed with its points in the stove, and the wool which is upon it remains outside of the stove, but will become slightly warmed. The other comb, which was heating whilst the first was filling, is now filled in turn, in the same manner as the first, and is then put to heat with the wool upon it, and whilst this is going on, the workman occupies himself in making a handful ready for the next combing.

When both combs are properly warmed, the comb holds one of them with his left-hand over his knee, as he is seated on a low stool, and with the other comb held in his right-hand he combs the wool upon the first, by introducing the points of the teeth of one comb into the wool contained in the other, and drawing them through it; this is repeated for 14 or 15 strokes, until the fibres of the wool are separated, disentangled, and laid parallel. In combing, he di-

rects the combs sometimes with the teeth of one parallel to the teeth of the other, and sometimes with the teeth of the two combs at right angles, or in a cross direction; but in all cases he must take care to begin gradually, by introducing the points of the teeth, first into the extremity of the wool which is contained in the teeth of the comb, and then penetrating deeper into the wool at every succeeding stroke, till at last he works the combs as near as he possibly can without actually bringing their teeth in contact: without this precaution, he could not draw the comb through the wool without breaking the fibres, and tearing the wool out of the teeth of the comb; but if he proceeds cautiously, the wool will be disentangled, separated, and straightened.

During the working, he frequently changes the combs, so as to work the wool upon both combs; but as the wool will gradually accumulate upon that comb which is most worked, he manages them so that at the end of about 35 or 40 strokes nearly all the wool will be gathered upon one of the combs, and will hang from its teeth in a fair lock of straight and regular wool. This comb he puts to heat for a moment, then fixes it to the post, and proceeds to draw off the wool from the comb in a sliver. To do this, he takes hold of the wool which projects from the teeth with the fingers and thumbs of both hands, and draws it away from the teeth of the comb in a direction perpendicular to their length, without sliding it off their points: as the wool comes away, he takes fresh hold, always seizing the wool at a given distance from the teeth. A portion of the wool which consists of short fibres will not come off, because it does not reach to the place where the comb grasps the wool; it therefore remains in the teeth of the comb, and is drawn off afterwards. This short wool, which is called noil, is unfit for worsted spinning; it is composed in part of the short fibres which are naturally intermixed in the long ones, and also of the fragments of long fibres which are broken in the process of combing. The quantity of the noil depends upon the kind of wool, and also on the care with which the comb has conducted his process; but it will seldom exceed $\frac{1}{4}$ th or $\frac{1}{3}$ th of the quantity of the raw wool by weight.

The wool which is drawn off from the comb forms a continued sliver or band, the fibres of which are straight and parallel, but not sufficiently so for spinning; it is therefore combed over again, and frequently it is repeated a third time. The first combing is called hacking, and the slivers produced by it are extended five together upon a table; then holding them down with one hand, they are broken again into handfuls by drawing them with the other. These are combed again in the manner before described, but the heat given to the combs is much less. The ultimate sliver, which is drawn off from the comb the last time, should be very even, and composed of long and parallel fibres. On examining it against the light, every part should appear equally dense, without any entanglements of the fibres, for on these particulars the perfection of the spinning will in a great measure depend.

The combed wool produced from sixteen pounds of wool usually weighs eleven or eleven and a half pounds, for about two pounds are lost in washing, and the rest in noil and waste in the combing. When the combing is finished, the slivers are formed into six parcels, each containing ten or eleven slivers, which are rolled up together into a ball, and ticketed with their weight and quality, the wool-comber's mark, and wool-stapler's mark. In this state, combed wool is called tops or Jersey, and is sold to the spinners in the country, and in cottages, who spin it into worsted-thread by the simple hand spinning-wheel; but the manufacturers who spin by machinery have wool-combers

at their mills, and they usually employ combing-machines in addition.

Combing-Machines.—The first combing-machine was invented by the Rev. Edmund Cartwright. His first two patents were in 1790, and he had another in 1792; but the machine was not rendered perfect, or brought into extensive use, till a later period: and in 1802 he obtained an act of parliament to renew or extend the term of his patent. The specification which he enrolled in consequence contains drawings and descriptions of machines nearly of the same kind as those which are now in use at many of the great worsted-mills, and which we shall describe. Mr. Cartwright proposed to form the raw wool into continued slivers, by joining the pieces of wool together, and slightly twisting them, and in this state they could be presented to the combing-machine; but as this plan was not found to succeed, it was found necessary to comb the wool first by hand, in order to reduce it to slivers. This is still the common practice, and takes away great part of the advantage of the machine; but we have seen a preparing-machine for this purpose, which operated very well upon the raw wool. The inventor's name we have not learned; but the rudiments of it are to be found in Mr. Cartwright's specification of 1790.

Preparing-Machine.—The raw wool is spread upon a horizontal feeding-cloth, which is extended over two rollers, and circulates upon them: by its motion, the wool is carried forwards, and presented to a pair of fluted rollers, which draw it in. This feeding-cloth is situated at the top of the machine, at the height of about five feet from the floor, so as to allow room for the rest of the machinery beneath it. A principal part of the machinery is carried by a horizontal wheel of five feet diameter, which is mounted upon a vertical axis, and is turned rapidly round by the mill. This wheel carries four porcupines, which are small cylindrical rollers, armed with spikes or teeth rather hooked. The rollers are situated horizontally in the plane of the wheel, with their length nearly in the direction of radii. They are about seven inches in diameter, and fourteen inches long, and are fixed upon horizontal spindles, which proceed from the circumference of the great wheel nearly to its centre, one extremity of each spindle being sustained by the rim of the wheel, and the other in a support fixed to the perpendicular axis. The porcupines are fixed on the ends of the spindles, near the circumference of the wheel; and on the opposite end of each spindle is a small cog-wheel, to work in a worm or endless screw, which is fixed concentric with the axis, being cut on the outside of a hollow tube, through which the vertical axis passes.

By this means, the four porcupines which the wheel contains have a two-fold motion, *viz.* they are all carried round in a circle by the motion of the wheel, and at the same time each one has a slow rotative motion on its own axis, in consequence of the cog-wheels, which work in the threads of the fixed worm.

The feeding-cloth is so situated, that the four porcupines in the great wheel will pass in succession exactly beneath the fluted rollers, which take the wool from the feeding-cloth; and the teeth of the four porcupines being sharp-pointed, and rather bent forwards at the points, they penetrate and catch the wool as it comes through these fluted rollers, and hangs down from them. A portion of wool is thus carried away by each porcupine every time it passes beneath the fluted rollers; but by the slow revolving motion of the porcupines on their own axes, each one presents a different row of teeth every time, and thus by degrees they become clothed with the wool which they take up.

This wool they deliver to a larger porcupine, which is placed beneath the revolving-wheel, or on the opposite side to the feeding-cloth. This porcupine is a cylinder nineteen inches diameter, and fourteen inches long: its axis is placed horizontally, and directed nearly to the centre of the vertical axis; so that the small porcupines will be parallel to the large one when they pass over it. The great porcupine is furnished with rows of teeth exactly similar to those of the small ones, which teeth are not very numerous, but large and sharp-pointed, and rather hooked, with the points forwards. When the small porcupines pass over the large one, there is so little clear space between their teeth, that the wool which is contained in the teeth of the small ones will be taken off by the large one, and remain in its teeth. The reason of this is, that the teeth of the large porcupine present themselves to the teeth of the small ones with the points forwards, and the small porcupines at the same time move with the points of their teeth backwards. It was before stated, that the porcupines move with the points forwards when they take the wool from the feeding-rollers, but this wool is applied on the upper side of the porcupines, and the great porcupine is at the lower side; hence the direction of the teeth is reverse in the two cases, and occasions the wool to be given to the great porcupine, a small quantity at a time, from each of the small porcupines, as they pass over it. The great porcupine being turned slowly round upon its axis clothes itself with the wool in a continued fleece, and this is drawn off from its teeth by a pair of fluted rollers, between which it passes in a continued sliver or band; this band is also conducted through a short tube, which revolves round its axis, and rolls up the sliver, to make it adhere better together in a round and compact form.

The action of this machine is not to comb the wool, but to divide the mass of raw wool, which is spread on the feeding-cloth, into a great number of small and equal portions by the successive strokes of the small porcupines; these portions are again mixed together in one film of wool upon the great porcupine, from which the wool is drawn off in a continued sliver, and as much twist is given to it as is requisite to make the sliver sufficiently compact to submit it to the combing-machine.

Cartwright's Combing-Machine, or Combing-Table; called also amongst the workmen *Big Ben*.—In *Plate II. fig. 1. Worsted Spinning*, is a horizontal plan of the machine, which exhibits nearly all its parts; we have also given a perspective view in *fig. 2.* of the operative parts, as they would appear if detached from the framing which sustains them. *A A* is a circular ring of wood, which is fixed down on the framing; *B B* is a similar ring, which is fitted into the fixed ring, with liberty to turn round within it. The interior of this ring is furnished with a row of comb-teeth, with the points directed to the centre, and there are two other rows of shorter teeth beneath, so as to make three circular rows of teeth. This forms a large circular comb, called the *combing-table*, about five feet diameter; it is moved slowly round in the direction of the arrow by means of a pinion, which works in to a ring of cogs, fixed in segments within the circular comb beneath the row of teeth, as is shewn in the section, *fig. 3.*

The wool is filled upon the teeth of the circular comb by means of two machines *F* and *G*, called *crank-lashers*. These supply the wool by lashing or throwing the lock of wool upon the teeth of the comb, and then drawing up the wool from the comb, with a motion very similar to that of the hand of the workman in filling the combs, as we have before described. The *crank-lashers* repeat their strokes with great rapidity; but as the comb-table is kept in con-

tinual motion, the wool which is lashed upon the teeth by the first crank-lasher *F* is carried away, and in its course comes beneath the other crank-lasher *G*, by which more wool is filled upon the teeth, and they receive the intended portion. This wool, by the rotation of the comb-table, is then carried beneath a small comb *K*, which works by a crank movement, but with its teeth always horizontal; they penetrate through the wool, and then rise up so as to comb it. After this operation, the wool is taken off from the teeth of the comb-table between a double pair of fluted rollers *N*, situated immediately over the comb-teeth; these draw off the combed wool in a continued sliver, which is conducted through another pair of plain rollers *R*, and falls into a tin can placed there to receive it.

This machine was not found capable of combing the raw wool, chiefly because the comb-teeth are not heated, and also because the actions of lashing on the wool, and afterwards combing it, begin to act upon wool, at first with their full force, and break the fibres if they are entangled together; hence it is found best to comb the wool by hand once over, or for fine goods twice. The wool is thus formed into slivers, which are joined together, by laying them on a table, with the ends lapped over each other; and rolling them together, they will join into one long sliver. Three of these slivers are put into tin cans *ii*, which are placed upon a circular table *I*, and carried upwards to the crank-lasher *F* or *G*, which are both of similar construction. The table *I* is mounted on an axis, so as to be capable of turning slowly round horizontally, in order to twist the three slivers together into one; but in the machines which we have seen in use, this movement is commonly neglected, for if the slivers are prepared by hand-combing, as we have before described, they will hang together without twisting.

The slivers, which are carried up from the cans to the crank-lasher (see *fig. 3.*), first pass over a roller at *e*; the axle of this roller is also the fixed centre of motion of a trough *H*, which forms one part of the crank-lasher. The sliver of wool is conducted along the trough *H*, and then turns over a second roller at *f*; the centre-pin of this roller is the joint, which unites the end of the trough *H* with a moveable frame *dd*, which has a tube *g* fixed in front for the sliver of wool to pass through. A little below the middle of this frame *dd* are holes through its sides, to receive the pin of a crank *bb*, of which the central axis is supported in bearings screwed to the frame of the machine, and it is turned round by the power of the mill. By means of a pair of bevelled wheels *D* and *E*, *fig. 1.* the cranks of the two crank-lashers are connected together, and have a common motion, but in a direction at right angles to each other. At the lower end of each of the moving frames *dd*, a pair of fluted rollers *i* are fixed, which draw the sliver between them. The rollers are put in motion by means of a cog-wheel *k*, fixed on the extremity of the axis of the lower roller; this is turned by a small pinion, fixed at the end of an axis, which passes through the frame *dd*, and which at the opposite end has a wheel *h*, that receives motion from a pinion fixed fast to the pin of the crank. The upper of the two fluted rollers is pressed down against the lower one by springs, which bear on its pivots with sufficient force to hold the wool firmly between them, and draw the sliver forwards when they turn round.

The motions of the crank-lasher are not easy to be understood from a verbal description. It must be recollected, that the upper end of the frame *dd* which carries the rollers, being jointed to the end of the trough *H*, it must always move in the arch of a circle, as shewn by the dotted lines, *fig. 3*; the centre of this arch is *e*: also that the middle part of the frame *d*, where the crank-pin passes through

it, must describe a circle when the crank revolves: in consequence, the rollers *i*, which are at the lower end of the frame, will move in a curve, as shewn by the dotted lines. It is an oval or distorted ellipse, with the longest diameter horizontal.

At the same time the fluted rollers circulate in this orbit, they are in continual motion on their own axis, by the communication of wheel-work before described, and they draw the sliver of wool down the tube *g*; the end of the sliver, which projects from below the rollers, hangs down from them in a lock, and by the motion of the crank-lasher this is thrown against the points of the teeth in the comb-table. At the period when the wool is thus thrown on the teeth, the rollers are moving nearly in an horizontal direction, so as to draw the wool in the direction of the length of the teeth, and they penetrate the wool; but as the rollers proceed in their elliptic orbit, they begin to rise and draw the wool upwards away from the teeth in an inclined direction, as is evident by tracing the dotted course marked out for the rollers. By thus drawing up the wool between the teeth, a portion of the wool will be left in them; the rollers then rise up rapidly in their oval course, and the wool is raised quite above the teeth; the rollers then move forwards to make another stroke, and during such advance, the rollers, being in continual motion, draw forwards the sliver of wool, and the end hangs down ready to be lashed on the teeth of the comb next time.

The motions of the small comb *K* must be next described. The whole machine receives its motion by means of a wheel or pulley *c*, *fig. 1*, upon the axis of the crank for the lasher *G*; *D* and *E* are the bevelled wheels by which the other crank is turned; at the extreme end of the axis *C* is a pinion, which turns a bevelled wheel *L*, and on the axis of this is a wheel turning two others *MM* of equal size; on the extremities of the axes of the wheels *MM* are two cranks *ll* of equal radii, which are both jointed to an iron bar *mm*, and both turning round together in the same direction, they cause the bar to move in a direction parallel to itself, and every part of the bar describes a circle equal to the radius of the cranks. The small comb *K* is fixed to this bar, and partakes of its motion, whereby the points of its teeth are carried horizontally into the wool contained in the teeth of the great comb, then rise upwards and draw through the fibres, in order to comb them.

In order to remove the little comb when it becomes filled with wool, it is attached to the bar *m* by means of a comb-holder or socket *L*, which has a groove at each end to receive the little comb, and it can be mounted or withdrawn at pleasure. This socket *L* is moveable upon a horizontal pin fixed at the end of the bar *m*, so that it can be turned with either end upwards; and as the little comb can be fixed at either end of the socket, a spare comb is placed in the upper groove of the socket, whilst the lower groove holds the comb which is in use; but when this becomes filled with wool, which it has gathered from the comb-table, the socket *L* is inverted by turning it half round upon its centre-pin, and by this means the fresh comb is brought down into use, and the other can be taken away to clear off the wool from it. There is a small bolt fixed to the pin on which the socket *L* turns, which can be shot into a notch when the socket is in a perpendicular position, and will then hold the socket fast from turning, and keep the comb in a proper position for its work. In this way, the little comb can be taken away and replaced by a fresh one as often as is necessary, without stopping the machine, for the small comb does not move very quick. The same boy who attends to change the combs, when necessary,

also sets up the wool in the great comb-teeth with a small scraper, so that the small comb will penetrate through it with more certainty and effect. The plane of the rows of teeth in the small comb is not horizontal, or parallel to the teeth of the combing-table, but inclined thereto, so that those teeth of the small comb which first come into action upon the wool do not penetrate deeply into it; but as the comb-table turns round, the wool advances beneath the small comb, and is operated upon those teeth which go deeper, and the last teeth of the comb go as deep as they can, not to touch the teeth of the comb-table.

The wool is now combed, and only remains to be drawn off in a continued sliver; this is done by the drawing-off rollers *N*, which are fluted iron rollers, placed horizontally over the comb-teeth, and nearly in the direction of a radius of the comb-table: they are supported in an iron frame, and are turned round by a pair of bevelled wheels from a vertical axis *P*. This axis extends the whole height of the machine, and is put in motion by means of a pair of bevelled wheels, and an oblique axis *Q*, which is turned by a bevelled wheel and pinion on the extreme end of the axis of the first crank-lasher.

The great comb receives its motion from the perpendicular axis *P*, which turns a large wheel *T* by a pinion on the lower end of it: on the upper end of the axis of this wheel is the pinion which works in the ring of teeth within the comb-table: in this way, a very slow motion is given to the comb-table. There are two pairs of drawing-off rollers *N*, situated close together, and parallel to each other; the first pair are put in motion as we have described, and the back pair are turned by means of equal cog-wheels, so that they move with the same velocity.

The wool upon the comb-table is gathered in the hand, to form a sliver, and the end is introduced between the rollers, which continually draw off the wool as the comb-table turns round. After passing through both pairs of rollers, the sliver is conducted through a forked iron, then through a round wooden tube, and is at last delivered by two plain wooden rollers *R* into a tin can placed beneath to receive it. These rollers are also turned by bevelled wheels on the perpendicular axis *P*. The drawing-off rollers only take away the long wool, the fibres of which are long enough to reach to the rollers. The two rollers composing the front pair of drawing-off rollers are not placed immediately over each other, but the upper roller overhangs the lower one, so that the plane in which the axes of the upper and lower rollers are both situated is inclined at about an angle of 45 degrees to the plane of the comb-table: by this means, the wool is drawn off from the comb, at an angle of 45 degrees, to pass between the rollers.

The noils, *i. e.* the short wool and broken fibres, which will not reach the drawing-off rollers, remain in the teeth of the comb-table, and also as much of the long wool as is on the lower side of the comb, and these are called backings: both are taken off by a boy, who is seated for that purpose within the circle of the comb-table; he first draws off the backings from beneath the comb, and then, with one hand above the teeth, and the other below, he draws off the noils.

These two sorts of wool are handed to a boy on the outside of the machine, who puts them into separate boxes. The backings are filled on the small combs before they are put into the machine, and become somewhat combed by the action of the small comb: when the small combs are removed from the machine, the wool upon them is further combed by hand, and then drawn off from them in a continued sliver, by means of an additional piece of machinery, which is at the side of the machine.

This combing-machine is found to break the fibre of the wool, and it increases the quantity of noil very much, unless the wool is previously combed once or twice by hand; and as it then becomes only a substitute for the second or third combing, it saves little or no expence. The advantage of the machine is found, in the great regularity and equality of the sliver which is produced by it, a circumstance of particular importance for fine spinning. In combing by hand when the sliver is drawn off, those fibres which the comb first takes hold of are longer than the others; then as the sliver continues to be drawn, shorter fibres are found in it, and the shortest are left of all. These are called the long and short ends of the sliver; the short end is always marked by twisting or rolling it up, in order that when the slivers are joined together into one for spinning, the long and short ends may be equally intermixed and dispersed throughout the whole length. In drawing off the wool from the combing-machine, the long and short fibres are intermixed and taken up together, so that the sliver is of very equal texture.

There have been several other attempts to make combing-machines which deserve notice, though they have not come into use.

Messrs. Wright and Hawkley had a patent in 1793 for a combing-machine; and Mr. Toplis of Cuckney had also a patent of the same date, which contains some good ideas. Mr. Hawkley, in 1797, had a patent for improvements on Cartwright's: the principal one was, to make the combing-table by the combination of a number of small combs, which could readily be applied to the table, or detached at pleasure. If this would allow the combs to be heated, as the inventor proposed, they would work much better.

Mr. Amatt had a patent in 1795, and Mr. Pearce in 1798: after this time, Mr. Cartwright's machines had received some improvements from Mr. Hawkley, and came into use; and we find less speculation on the subject.

Gilpin's Combing-Machine.—In 1811, Mr. George Gilpin of Sheffield perfected a very ingenious machine, which combed the raw wool in a most complete manner. We do not hear that this machine is yet come into use, although we have no doubt of its answering the purpose, having frequently examined it while at work: its only fault was a complication of parts, which might be easily removed.

The outline of this machine is taken from that of Mr. Toplis in 1793, but is very much improved and perfected. *Fig. 4. of Plate I. Worsted,* is a sketch of the principal parts. The machine works with eight combs at once, which are of rather larger size than the ordinary hand-combs, the rows of teeth being twenty inches long. These combs are fixed upon two reels or frames A, B, which revolve upon their axes by the power of the mill; four combs, D and E, are fixed upon each reel, and in such position that both ends of the comb-teeth, *viz.* the points and roots, are equally distant from the centre of the reel to which they are fixed; and the reels, with the combs fixed upon them, form two revolving wheels or frames. The combs D and E are so made, that they can be detached from the reels, or replaced and fixed fast in a moment, by the attendants; and they can, therefore, be heated in a stove, in the same manner as the hand-combs. The wool is also filled upon the combs by hand, and the combs and wool are heated in the usual manner before they are put into the machine, in order to comb the wool.

One of these reels A is simply turned upon its axis, but the other reel B has a curious compound motion given to it by the machinery: thus it revolves on its own axis; but the axis also advances to, and recedes from, the other reel with

a motion parallel to itself, which is repeated four times in every revolution. Whilst B advances towards A, it moves with only one-third of the velocity with which it returns from A. The advancing movement is of a limited and constant extent; but at the same time, there is a third movement which regulates this extent, so that at every succeeding stroke which the machine makes, the two reels will approach nearer together.

Suppose all the combs filled with wool, and mounted in their places upon the reels, the machine is then put in motion, and the two reels A and B turning round in opposite directions, their combs D and E meet each other; and by the compound movement of B, (*viz.* advancing slowly towards A, and turning round at the same time,) the combs D and E approach in such a manner, that the points of each comb penetrate the wool which is in the other comb, and this is reciprocal of both combs. When the teeth are thus entered into the wool, the moveable reel B retreats quickly from the other, and the teeth, by drawing through the wool, comb and separate its fibres.

The circular motion of both reels is not regular and equable, but is communicated by means of elliptical cog-wheels, which occasion the reels to move round very slowly, at the moment when the comb of the reel B is drawing out or combing the wool; but this motion being finished, the reels begin to turn round more rapidly, and at the same time the reel B approaches towards A with a slow movement, in order to present another pair of combs to each other, which meet; and each one penetrates the wool which is upon the other, and then the reel B draws out to comb it, in the manner before described.

In this way they continue to make successive strokes, until the wool is sufficiently combed: the machine is then stopped, and the combs taken off one by one, to be replaced by others, which are filled with fresh wool, and properly heated.

There is likewise another movement of the reel A, which we have not yet mentioned: the axis of that reel has a slow motion backwards and forwards, endways in the direction of its length, for a short distance. The intention of this is, that the same parts of the combs shall never come opposite to each other at two successive strokes.

It should be observed, that when the machine is first set to work, the combs at their point of meeting do not come within three or four inches of each other, and the points only penetrate amongst the longest fibres of the wool upon the combs; but at every stroke which is made, the combs advance nearer together, and take deeper into the wool, until, after a certain number of strokes are made, the combs approach as near as they can without touching. They continue to work in this manner for some time, and when the intended number of strokes is made, a bell rings as an indication that the machine should be stopped. This is done by drawing a lever, and in consequence the machine will stop itself in the exact position for changing one of the combs on each reel. These are removed, and others ready filled with wool and heated are put on in their places, which being done on both reels at the same time by two persons, is only the work of a moment. The machine is then put in motion again, but by the machinery it will stop itself again at the required position for changing the next pair of combs; it is then put forwards, and so on, until all the eight combs are changed.

The combs which are removed from the machine are put into the stove to heat for a few moments, and then the wool is drawn off from them by a separate machine. The head of the comb is here placed in a perpendicular groove, so that its teeth stand horizontal; and a piece

of metal, which is fixed to the head of the comb, and projects therefrom like a tooth, enters into the spiral groove of a screw, which stands in a perpendicular position, and is continually turned round by the machinery. By this means, the comb is regularly and slowly let down in the groove, from top to bottom. A pair of fluted rollers is placed horizontally, and parallel to the teeth of the comb, in such a position that the comb, in descending, will pass with its teeth at a proper distance from them, to draw off the wool in a sliver. After passing through these fluted rollers, the sliver is conducted through a perpendicular revolving tube, which gives a roundness to it, the same as it would acquire by being rolled between the hands, and then it is conducted between a pair of plain rollers, which deliver it into a tin can placed before the machine.

A wooden roller is placed above the fluted rollers, with eight pieces of board projecting from it in the direction of radii. When the roller turns round, these boards act to stroke the wool upon the comb, and raise it into a proper situation to be drawn off by the fluted rollers.

The combs are prepared for drawing off the wool, by heating them as before mentioned, and by sliding the wool from the roots of the teeth half way towards their points. In this state, the combs are carried one by one to the drawing-off machine, and the head of one comb is put into the top of the perpendicular groove: it will be prevented from falling down in the groove by the projecting tooth, which enters the spiral groove of the perpendicular screw. The wool is gathered up and introduced between the fluted rollers; the machine is then put in motion, and by means of the screw the comb is gradually lowered down, and the wool is drawn off from it in a sliver, which is rolled up into a compact form by the revolving tube, through which it passes, and is delivered into the can by the plain rollers.

The attendant holds another comb ready to follow the first, and when the first has descended to a certain point, he slips the next comb into the perpendicular groove, so that it rests upon the former, and the wool upon the two combs joins as it were in one. The stroker, when they pass before it, lays the fibres all one way, and the wool is drawn off by the rollers in a continued sliver, which does not present the slightest appearance of joinings. Another comb is then put in, and the wool joins to the former, and so on. The backings, or wool at the back of the comb, are drawn off by the boy stationed behind the machine; and the combs, as they come through below, are received by boys, who afterwards take away the noil or short wool which remains in the teeth, and then put the combs back into the stove to heat them, ready to be filled again, in order to proceed with another combing. When the wool of all the eight combs is drawn off, the motion of the drawing-off machine is stopped at the moment when the eighth or last comb has descended half way through its course. In this state, the machine waits till another combing is finished, and then the succeeding comb being placed on the top of that one which continues in the machine, the continuity of the sliver will be preserved.

The inventor of this machine states in his specification, that for common work the wool only requires to be operated upon once by the combing-machine; and in that case, the machine must be adapted to make twenty-four strokes of each pair of combs before the bell rings. For medium work, such as would require to be combed twice over, in the usual manner of hand-combing, it must be combed twice over by the machine: thus, after having been combed once in the manner before described, the sliver of wool is broken up into handfuls, and filled on the combs again by hand as

before, and combed over again in a similar manner; but the combs are left heated for the second time of combing. By changing a wheel, the machine should be adapted to make only fourteen or sixteen strokes before it stops, when it is intended to comb twice over. The wool intended for the finest spinning should be combed three times over, and the machine should be set to make fourteen or sixteen strokes of each pair of combs.

The machine has also two different movements for the drawing out of the moveable comb-reel: in one, the motion is over a space of ten inches, and is adapted to comb such wool as is six or eight inches length of staple, and is called wether wool; but by a slight alteration, the excursion of the moveable reel can be increased to thirteen inches, and is then adapted to comb hey wool, or wool which is from eight to eleven inches length of staple.

Mr. Gilpin's machine has the advantages of heating the combs and of filling them by hand, both of which are essential to any machine which is proposed to comb the raw wool. The filling is an operation which requires discretion, if it is expected that the long fibres shall be preserved without breaking. The person who fills the wool on the teeth takes a greater or less lock of wool in his hand, according to the condition of it, and the degree of entanglement: also in drawing it between the comb-teeth, the force is proportioned to what the wool will bear. Mr. Gilpin's specification states, that under certain circumstances, when the wool will not wash well, but remains taggy, it is advisable to fill it upon the combs, and slip it off; then fill it again, preparatory for the machine. As the object of this first filling is chiefly to warm the wool, the end may be in part attained by laying the wool upon the top of the stove for a few minutes before it is filled.

Planking.—Let us suppose that the wool is combed either by the hand, or by the machine, and we will proceed to explain the means of preparing it into a thread. The combing-machines reduce the wool into a continued sliver, which is ready for the drawing-frame; but the short slivers produced by the hand-combing must be first joined together by what is called planking. These slivers are rolled up by the combers, ten or twelve together, in balls called tops, each of which weighs half a pound: at the spinning-mill these are unrolled, and the slivers are laid on a long plank or trough, with the ends lapping over, in order to splice the long end of one sliver into the short end of another. The distinction of the two ends of the sliver has been before explained; the long end being that which was first drawn off from the comb, and contains the longest fibres of the wool; the short end is that which came last from the comb, and contains the short fibres. The wool-comber lays all the slivers of each ball the same way, and marks the long end of each by twisting up the end of the sliver. It is a curious circumstance, that when a top or ball of slivers is unrolled and stretched out straight, they will not separate from each other without tearing and breaking, if the separation is begun at the short ends, but if they are first parted at the long ends they will readily separate.

Breaking-Frame.—Here the slivers are planked or spliced together, the long end of one to the short end of another; they are immediately drawn out and extended by the rollers of the breaking-frame. A sketch of this machine is given in *Plate II. fig. 5*; it consists of four pairs of rollers, A, B, C, D. The first pair A receives the wool from the inclined trough E, which is the planking-table. The slivers are unrolled, parted, and hung loosely over a pin, in reach of the attendant, who takes a sliver and lays it flat in the trough, and the end is presented to the rollers A, which being in

motion will draw the wool in; the sliver is then conducted through the other rollers, as shewn in the figure: when the sliver has passed half through, the end of another sliver is placed upon the middle of the first, and they pass through together; when this second is passed half through, the end of a third is applied upon the middle of it, and in this way the short slivers produced by the combing are joined into one regular and even sliver.

The lower roller C receives its motion from the mill, by means of a pulley upon the end of its axis, and an endless strap. The roller which is immediately over it is borne down by a heavy weight *e*, suspended from hooks, which pass over the pivots of the upper roller. The fourth pair of rollers D moves with the same velocity as C, being turned by means of a small wheel upon the end of the axis of the roller C, which turns a wheel of the same size upon the axis of the roller D, by means of an intermediate wheel *d*, which makes both rollers turn the same way round. The first and second pairs of rollers, A and B, move only one-third as quick as C and D, in order to draw out the sliver between B and C to three times the length it was when put on the planking-table. The slow motion of the rollers A is given by a large wheel *a*, fixed upon the axis of the roller A, and turned by the intermediate cog-wheels *b*, *c*, and *d*; the latter communicates between the rollers C and D. The pinions on the rollers C and D being only one-third the size of the wheel *a*, C and D turn three times as fast as A, for *b*, *c*, and *d*, are only intermediate wheels. The rollers B turn at the same rate as A. The upper roller *e* is loaded with a heavy weight, similar to the rollers A; but the other rollers, B and D, are no farther loaded than the weight of the rollers.

The two pairs of rollers A B and C D are mounted in separate frames, and that frame which contains the third and fourth pairs, C D, slides upon the cast-iron frame F, which supports the machine, in order to increase or diminish the distance between the rollers B and C. There is a screw *f*, by which the frame of the rollers is moved, so as to adjust the machine according to the length of the fibre of the wool. The space between B and C should be rather more than the length of the fibres of the wool. The intermediate wheels *b* and *c* are supported upon pieces of iron, which are moveable on centres: the centre for the piece which supports the wheel *b* is concentric with the axis of the roller A; and the supporting piece for the wheel *c* is fitted on the centre of the wheel *d*. By moving these pieces, the intermediate wheels *b* and *c* can be always kept in contact, although the distance between the rollers is varied at times. By means of this breaking-frame, the perpetual sliver which is made up by planking the slivers together is equalized, and drawn out three times in length, and delivered into the can G.

Drawing-Frame.—Three of these cans are removed to the drawing-frame, which is similar to the breaking-frame, except that there is no planking-table E. There are five sets of rollers, all fixed upon one common frame F, the breaking-frame which we have described being the first. As fast as the sliver comes through one set of rollers, it is received into a can, and then three of these cans are put together, and passed again through another set of rollers. In the whole, the wool must pass through the breaker and four drawing-frames before the roving is begun. The draught being usually four times at each operation of drawing, and three times in the breaking, the whole will be $3 \times 4 \times 4 \times 4 \times 4 = 768$; but to suit different sorts of wool, the three last drawing-frames are capable of making a greater draught, even to five times, by changing

the pinions; accordingly the draught will be $3 \times 4 \times 5 \times 5 \times 5 = 1500$ times.

The size of the sliver is diminished by these repeated drawings, because only three slivers are put together, and they are drawn out four times; so that in the whole, the sliver is reduced to a fourth or a ninth of its original bulk.

The breaking-frame and drawing-frame, which are used when the slivers are prepared by the combing-machines, are differently constructed; they have no planking-table, but receive three of the perpetual slivers of the combing-machine from as many tin cans, and draws them out from ten to twelve times. In this case, all the four rollers contribute to the operation of drawing; thus the second rollers B move $2\frac{1}{2}$ times as fast as the rollers A; the third rollers C move 8 times as fast as A; and the fourth rollers E move 10 times as fast as A. In this case, the motion is given to the different rollers by means of bevelled wheels, and a horizontal axis, which extends across the ends of all the four rollers, to communicate motion from one pair of rollers to another.

There are three of these systems of rollers, which are all mounted on the same frame; and the first one, through which the wool passes, is called the breaking-frame, but it does not differ from the others, which are called drawing-frames. The slivers which have passed through one system of rollers are collected four or five together, and put through the drawing-rollers. In all, the slivers pass through three drawings, and the whole extension is seldom less than 1000 times, and for some kinds of wool much greater.

After the drawing of the slivers is finished, a pound weight is taken, and is measured by means of a cylinder, in order to ascertain if the drawing has been properly conducted; if the sliver does not prove of the length proposed, according to the size of worsted which is intended to be spun, the pinions of some of the drawing-frames are changed, to make the draught more or less, until it is found by experiment that one pound of the sliver measures the required length.

Roving-Frame.—This is provided with rollers the same as the drawing-frames: it takes in one or two slivers together, and draws them out four times. By this extension, the sliver becomes so small, that it would break with the slightest force, and it is therefore necessary to give some twist; this is done by a spindle and flyer. (See *fig. 6*.) A B are the two pairs of rollers, between which the sliver is passed; the first rollers A turn round slowly, but the others B revolve four times as quick, to draw the sliver to four times its original length; and as fast as it issues from the roller, it is twisted by the motion of the spindle C, and wound up upon the bobbin *a*. The spindle C is put in motion by a whip-cord band, which passes round the pulley *e*, and also round the wheel D. This wheel is fixed on a vertical axis *c*, which has a pinion on the upper end, to give motion to the lower roller B, by means of a bevelled wheel upon the end of its axis. The opposite end of the axis has also a bevelled pinion upon it, to give motion to a bevelled wheel fixed upon an horizontal axis, which carries another bevelled pinion, to give motion to a bevelled wheel fixed upon the end of the axis of the back rollers A. The sizes of these wheels and pinions are so proportioned, that the back rollers A turn only once to every four turns of the front rollers B, as before mentioned.

The back rollers are capable of being set at a greater or less distance from the front rollers, according to the length of the fibres of the wool, and in all cases the distance should be rather more than the length of the fibres, but not a great deal.

The spindle is supported on its point, and sustained by a collar at the middle of its length. Upon the top of the spindle, the flyer *e* is screwed; it has two branches, which turn downward, and one of them has an eye at the lower end, through which the roving is conducted, in order to lay it upon the bobbin *a*. This bobbin is fitted loosely upon the upper part of the spindle, and rests with its weight upon a piece of wood projecting from the bobbin-rail *f*. The rail is made to rise and fall continually with a slow motion, so as to present every part of the bobbin in succession to the eye of the flyer, and thereby wind the roving upon every part of the length of the bobbin. The bobbin is not fixed upon the spindle, but is fitted loosely thereupon; and by resting upon the piece of wood which is fixed to the bobbin-rail, there is so much friction and resistance to the motion of the bobbin, that it gathers up the roving by winding it round itself as fast as the rollers give it out. The twist given to the roving is just enough to make it hang together, and one turn in each inch is usually enough. Some roving-frames are made with four pairs of rollers, and draw ten or twelve times; and in this way, it is not necessary for the sliver to pass so frequently through the drawing-frame.

Spinning-Frame.—This is so much like the roving-frame, that a short description will be sufficient. The spindles are more delicate, and there are three pairs of rollers instead of two; the bobbins which are taken off from the spindles of the roving-frame, when they are quite full, are stuck upon wires at *L* (*fig. 7.*), and the roving which proceeds from them is conducted between the rollers. The back pair *A* turns round slowly; the middle pair turns about twice for once of the back rollers; and the front pair *B* makes from twelve to seventeen turns for one turn of the back rollers *B*, according to the pinions which are employed, and these can be changed according to the degree of extension which is required.

The spindles must revolve very quickly in the spinning-frame, in order to give the requisite degree of twist to the worsted. The hardest twisted worsted is called tammy-warp, and when the size of this worsted is such as to be twenty or twenty-four hanks to the pound weight, the twist is about ten turns in each inch of length. The least twist is given to the worsted for fine hosiery, which is from eighteen to twenty-four hanks to the pound. The twist is from five to six turns *per* inch. The degree of twist is regulated by the size of the whirls or pulleys upon the spindle, and by the wheel-work, which communicates the motion to the front rollers from the band-wheel, which turns the spindles.

It is needless to enter more minutely into the description of the spinning machinery for worsted, because the construction is very similar to the water-frame for spinning cotton, invented by sir Richard Arkwright, and which is

fully described in our article *Manufacture of COTTON*. The differences between the two are chiefly in the distance between the rollers, which in the worsted-frame is capable of being increased or diminished at pleasure, according to the length of the fibres of the wool, and the draught or extension of the roving is far greater than in the cotton.

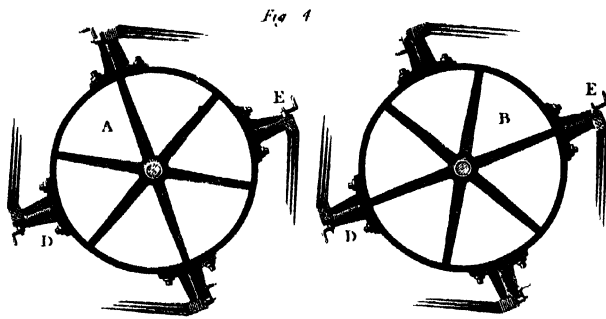
Reeling.—The bobbins of the spinning-frame are placed in a row upon wires before a long horizontal reel, and the threads from 20 bobbins are wound off together. The reel is exactly a yard in circumference, and when it has wound off 80 turns, it rings a bell; the motion of the reel is then stopped, and a thread is passed round the 80 turns or folds which each thread has made: the reeling is then continued till another 80 yards is wound off, which is also separated by interweaving the same thread; each of these separate parcels is called a ley, and when seven such leys are reeled, it is called a hank, which contains 560 yards. When this quantity is reeled off, the ends of the binding thread are tied together, to bind each hank fast, and one of the rails of the reel is struck to loosen the hanks, and they are drawn off at the end of the reel. These hanks are next hung upon a hook, and twisted up hard by a stick, then doubled, and the two parts twisted together, to make a firm bundle. In this state, the hanks are weighed by a small index-machine, which denotes what number of the hanks will weigh a pound, and they are sorted accordingly into different parcels. It is by this means that the number of the worsted is ascertained as the denomination for its fineness: thus No. 24. means that 24 hanks, each containing 560 yards, will weigh a pound, and so on.

This denomination is different from that used for cotton, because the hank of cotton contains 840 yards instead of 560; but in some places, the worsted hank is made of the same length as the cotton.

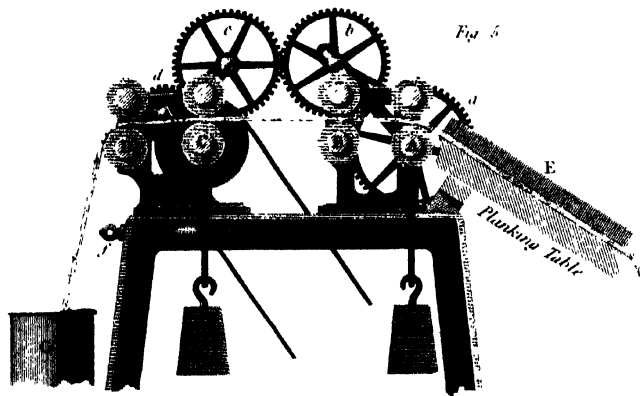
To pack up the worsted for market, the proper number of hanks are collected to make a pound, according to the number which has been ascertained; these are weighed as a proof of the correctness of the sorting, then tied up in bundles of one pound each, and four of these bundles are again tied together. Then 60 such bundles are packed up in a sheet, making a bale of 240 pounds, ready for market.

From this account of the processes of worsted spinning, it will be seen that they are very similar to those of cotton-spinning, after the first preparation of the wool by combing instead of carding.

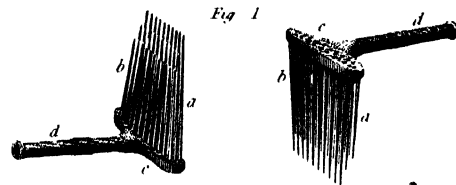
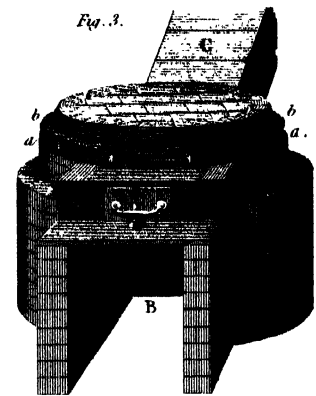
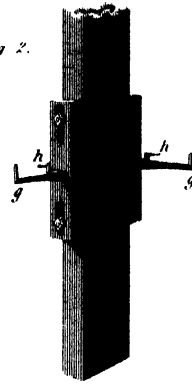
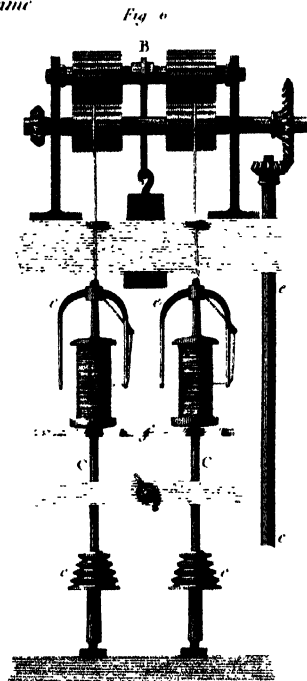
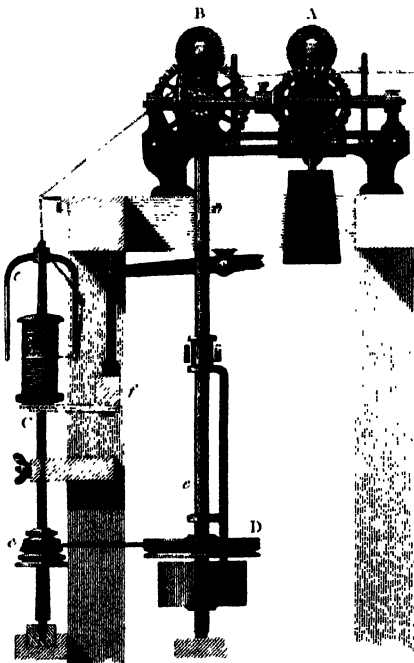
WORSTED-Cord, in *Sheep-Farming*, is a sort of cord which is sometimes used for tying round the necks of sheep affected with the scab, after it has been well smeared over with the common mercurial ointment of the shops, in order to cure them of that disease. See SCAB.



BREAKING Frame.



ROVING Frame



SPINNING Frame



Yufts

YUFTS, or *Russia Leather*, as it is called in England, are the chief products of the tanneries in Russia; and the principal places in which they are prepared, next to Moscow and Petersburg, are, Arsamas, Kof-troma, Yaroslaf, Pfcove, Kazan, Vologda, Nfhney-Novgorod, Vladimir, Ekatarinenburg, &c. Mr. Tooke has described the process by which they are prepared:—The raw ox-hides are first laid in running water, or in large tan-pits full of water dug in the earth for that purpose, to soak for a whole week; but in summer not so long. During this time they are daily taken out of the water, and scraped at a scraping-bench, or wooden horse. Having now been duly steeped, they are put into a ley, thus prepared: In other vats, likewise dug in the ground, and under cover, they mix two parts of good ashes with one part of unslacked lime, in boiling water, and sink the wet hides in this ley on a grating, which being suspended by cords, can be raised or let down at pleasure. In this vat the hides are laid again for about a week, though in warm weather less, in cold perhaps even longer. The sign that they have lain long enough in the ley is, that the hair can without difficulty be rubbed off with the hand, so that none remains. If the hides, after the expiration of a week, are not in that condition, fresh ashes are put into the ley, and the skin sunk in it. But if at length the hair be sufficiently loose, the hides are entirely taken out of the ley, and all the hair scraped off on a stretching-block, by means of blunt iron scrapers with two handles. The hair is washed clean, and sold for domestic uses. The hides, thoroughly cleansed from hair, are suspended in vats of clean water on a running stream, where they remain three days, diligently turning them to and fro, in order to purge them from the ashes and ley; afterwards they are hung up, and left to drain. The hides must now be scraped on the flesh side. To this end they employ either the aforefaid scraping-iron, or others sharper in various degrees. After this treatment, the hides are trampled. But calves-hides have another sort of preparation, which the yuft-tanners, in the interior towns of the empire, who mostly practise it, call *rakfcha*. This preparation is performed with the white excrement of dogs dried, which is dissolved in boiling water, and to a hundred hides about four vedros full of excrement is the rule. If here the right proportion

with the water be not found, the hides corrupt in this slime, the object whereof seems to be the complete freeing of the skin from the salts that adhere to it from the ley. The hides are left to lie twice twenty-four hours. With this is stirred a four gruel of oatmeal with warm water, and to three osmics, or eighths of a chetverik, three or four vedros of dregs of the common quas, which the people make of meal and a small portion of malt, put in the thin gruel, that it may quickly sour with the hides. To ten hides, the tanners usually reckon forty pounds of meal.

After the hides have soured, which is done in large vats, they are laid in other vats, and well steeped for two or three days in a strong tan-juice, sok, thoroughly boiled from good bark. When this is done they are brought straight to the tan. In the tan-pits, in which often some hundreds of hides are lying, is poured half water and half tan, or water boiled with tan, and a grating is hung in with cords, having one hide after the other spread upon it, thick strewed with good fine-pounded tan, and the grating constantly let deeper into the pit, till it be nearly full; yet so that the tan-liquor is always above the hides, which are then again sprinkled over with tan. In this tan the hides continue to lie a week; those of full-grown animals longer. On being taken out, they are washed and trampled on, which two workmen in a summer's day can perform with three hundred hides. The next day they are laid, in the manner above-described, in fresh tan. Thus they generally get four times successively fresh tan, and are every time rinsed clean. In the last tan they lie three weeks, or longer, are then finally washed, hung up, and, when they have tolerably drained, delivered to those workmen whose business it is, in particular workshops, to dye, dress, and wax the yufts, and to deliver the goods finished. It is to be observed, that the Russian yuft-tanners seldom use oak-tan, and never willingly. The choicest and best tan is that of the tschernotal, as they call it, or the black willow; and also the young bark peeled off from other shrubby willows, which are collected by the boors, dried in bundles, and brought in cart-loads to market. To ten hides, the tanners compute one and a half fathom of these bundles of willow-

bark, as they are laid one upon another for sale, through all the tana. It must not, however, be imagined that the excellence of the Russian yufts depends on this; for in Siberia, where are no oaks, and but few willows of any size, they tan yufts with only birch-bark, which are not much worse than the Russian. The bark is made small by either ordinary tan-mills, turned by horses or by water; or the tanner himself, in many towns where there are no mills, causes it, at unnecessary expence and labour, to be pounded in wooden mortars, or excavated blocks, with pestles, almost like those in the tan-mills, by day-labourers.

The dyeing of the yufts is performed in two ways, and of two colours. The commonest and most natural custom of giving the colour to the hides is, by sewing them together in pairs, the hair side inwards, while they are yet moist, round the edges, with rushes or stripes of bark, thus forming them into a bag or sack; into this sack the colour is put, the sack well shook, and the superfluous dye let to run out, whereupon the skins are dried. From this method of dyeing them, it seems to proceed that the yufts are called and taken by pairs. The other process, whereby much trouble, time, and colour are saved, and the edges of the skin entirely preserved, is the following: Each skin is hung upon a horse over a long trough, so that the hair side, which must be stained, appears outwards, pouring the dye upon it out of the dye-kettle, till the whole skin is dyed. The two colours given to the yufts are red and black. The red dye is thus prepared: Pound brasil-wood (sandal) in the pounding-mill, or with hand-pestles, as fine as the tan, and boil it in kettles. Previous to the dyeing, steep the skins in alum-water. It is calculated, that to each small yuft-skin a half, and to a large one a whole pound of logwood is put. But the latter are mostly coloured black. To a hundred yufts to be dyed red, four pounds of alum is sufficient. For dyeing black the brasil-wood is likewise used; but in the red dye, to a hundred skins three pounds of good iron vitriol is dissolved. After the first tincture the skins are dried, and afterwards on tables done over again with the same dye and rolled up, that they may thoroughly imbibe the dye. For heightening the colour this tincture is sometimes thrice repeated. When the skins are now tolerably dried, by hanging, that the colour may not fade, with the flesh side outwards, the yufts, still somewhat moist, are smeared over on tables that have ledges. There was a time when it was commanded by authority to use nothing but dolphin and seal-blubber for smearing them; but by that the yufts are harsher, and have not that yuft smell, which foreigners prize so much, unless the birch-tar, deggot, prepared in Russia, at least be mixed with it. At present this birch-tar alone is used for smearing. This done, the skins are cleansed from any impurities that may remain, and are sent to the dressing-house, where skilful workmen scrape them first with scraping-irons, having two handles, with the edge cross-wise on a stretching-bench, that a soft thin leather remains with a clear glossy surface, free from all impurities. Other workmen then take the clean-scraped yufts on large clean tables, sprinkle them on the flesh side with a gentle shower of fresh water from their mouths, and lay them slightly rolled up to moisten. This done, the skins are taken separately one after another, folded together, and worked and calendered in all directions, to make them soft and pliant. They are then curried with a kind of wooden curry-comb, with sharp irons fixed in leathers, like a card for carding wool, the skin being folded with the hair side outwards, by which the whole surface of the yufts acquire the cross-strokes or trellis-like marks they are always seen to

have. Some work the skins with the hands first dry, not sprinkling them till they are mangled with the card. Lastly, those skins which are too harsh and stiff to the feeling, are more or less sprinkled with linseed-oil, and thus are ready for the merchant.

In this connection we shall introduce from the same author an account of the Russian method of preparing and dyeing their sassian, maroquin, or Morocco leather, which are dyed at Astrachan of three colours, red, yellow, and black. The treatment of the red sassians, which are the most famous, is usually as follows:—The raw hides are first laid in large vats, and have river water poured upon them, in which they are left to soak for three or four times twenty-four hours. They are then taken out, the water is drained and squeezed from each skin, and are scraped one by one on the stretching-bank with scraping-irons, uraki, quite gently on the flesh side, in order to take away the grosser impurities, but principally for opening the skin, and to qualify it for the ensuing operation.

They now proceed to make the hair fall clean off, chiefly by the application of lime. To a hundred hides is stirred in about half a bushel of unslaked lime in vats with river water, and the hides are laid in so as that the lime may as much as possible be equally distributed over all of them. The Astrachan Tartars let the hides lie in this lime-pit frequently three weeks; but it is well known, that their sassians are so harsh and liable to crack, and even scorched by it, that they are fit for nothing, and can only impose upon an inexperienced purchaser. They then take out skins, wash them, and carefully scrape off the hair, now become loose, with wooden scrapers. It often happens, that the hair is not perfectly loosened by the first lime-ley, but that many tender stubbles and small hairs are left remaining. In this case, the hides must be put into fresh lime-ley, and be left perhaps two weeks in it; the hair then comes off, and the hair side of the skin gets a green and very white appearance, but the substance is then also very soft, and the sassians, by this corrosion of the lime, are very little durable in comparison of other kinds of leather.

The method now for taking the lime again out of the hides, is the second treatment with dog-excrement, or white gentian, which is carefully collected for this purpose. This excrement, which is indispensably necessary, is pounded, put into a narrow not very large vat, warm water poured upon it, the mass thoroughly stirred, and the cleansed hides are put with it into another vat, so as that the dissolved album grecum is spread and insinuated over and between every skin. In these ingredients, the skins must lie only twenty-four hours, or if the quantity of album grecum prove not rich, somewhat longer. The proportion here to be observed cannot be accurately ascertained; for the sassian-makers are guided generally by eye-measure, and observe only that the water be very thick and turbid, and consequently acrid enough. The hides come out of this corrosive much softer and thinner than they were, and are now freed from the force of the lime; but no time must be lost in endeavouring to extract the corrosive likewise, that the hide may not be even more ruined by it than by the lime. They are generally very careful that the hides lie not too long in this corrosive, which they judge of by their eye from the pliancy and suppleness of them. As soon as the skins are lifted out, the unclean moisture is carefully and forcibly pressed out, and they are laid without loss of time in a vat, wherein wheat-bran is stirred to a tolerably thick gruel with warm water; in this they lie again about thrice twenty-four hours, whereby all the former defects are completely remedied, and the substance of the

skin is softer and mellow. All these particulars are in some measure of no other service than to bring off the hair thoroughly clean from the skin.

Now follows the proper preparation of the skins taken out of the wheat-bran. This is done chiefly by honey. To eighty hides they take about twenty-five pounds of raw honey, boil it in a kettle, pour as much water to it as is necessary for giving it a due consistence, and stir it for a pretty long time boiling on the fire. They then let the kettle cool, till they can but just bear the hand in it, and then pour the still hot honey-water on the hides lying singly in little trays, by ladle-fuls, till they have thoroughly imbibed the honey-water. When all the skins are duly drenched, they are thrown into a dry vat all together, laying at top a board with weights upon it, and covering the whole vat with felt, carpets, or furs, that the vapour during the fermentation may not escape; and in this manner, the skins must ferment once more thrice twenty-four hours. By this means they acquire the grain. From the honey-vat they are rinsed clean in luke-warm water, wrung as dry as possible, and steeped immediately in a moderately strong pickle or brine made of common salt, in which they must be left five or six days. This time being elapsed, the skins are taken out of the pickle, and hung upon clean poles, that the brine may drain out, as it would be thought injurious to squeeze it out with the hands. This done, the skins have received their whole preparation, and may now be dyed red, but not yellow; because for the yellow saffians, as was said before, the preparation is of another kind.

For giving the red saffians the colour, nothing is used but cochineal, or, as the Tartars call it, kirmis, and that in the following method: First, they boil a quantity of the herb *salvia ericoides*, by the Tartars called *tshagan*, plentifully growing on the arid Astrachan salt-steppes. To about four Russian vedros of water is put of this dried herb somewhat less than a pound, and it is set to boil for a whole hour, whereby the water acquires a dark greenish colour, but betrays no acrimony to the taste. The saffian-maker only takes care that the water be not too deeply tintured, and that when dropped on the thumb-nail shews only a scarce perceptible green; and in case it have adopted too many particles of the colour, it is drawn off, and fresh water put, in which the herb must boil again, till the decoction has received the due degree of saturation. The herb is then with a scoop taken clean out of the kettle, and then the previously nicely powdered cochineal thrown into a kettle of four Russian vedros to about half a pound, well stirred, and fresh fire added, in which great attention must be paid, that the red scum, which arises from boiling, does not boil over, therefore constantly some is taken and again poured in, in order by this refrigeration to prevent the over-boiling, and to allay the foam. After boiling for about an hour and a half, the water has obtained a strong tincture; but as much of it is boiled away, the kettle is filled up again with the remaining decoction of the herb *tshagan*, and the thus attenuated colour boiled afresh, till it is seen that the cochineal is perfectly dissolved, and the colour become thoroughly bright. Upon this, to the whole kettle is put about two lots of pounded and burnt alum into the dye, with which it is to boil about a quarter of an hour, and then the fire is taken from under the kettle, leaving only some hot embers, that the dye may retain as much heat as the hand can but just bear. This done, the skins prepared for dyeing are taken in hand, the dye poured by ladles into trays, one skin folded together after another, with the hair side outwards, and then are worked in their portion of dye so long, till they have uni-

formly absorbed all the dyeing particles, and only somewhat of a pale moisture remains. The leathers being thus for the first time stained are quickly squeezed out, hung up singly across poles, and when they are all done, they are directly taken for the second time, and imbued in the same manner with dye, and this treatment is repeated for the third and the fourth time; so that each skin gets four ladles of the dye. From the fourth dye the skins are no more pressed out, but hung up entirely wet, to be ventilated, upon poles.

After the dye, the skins are once more curried with the leaves of the tan-tree, which the Armenians call *belgè*. The crushed or pounded dry leaves, which the Astrachan saffian-makers get from the Terek, are stirred in broad troughs to a thick gruel with river water, and the coloured skins laid in it, between each of them, leaving a sufficiency of the leaf-ooze; the tanner then goes barefoot into the troughs upon the skins lying on one another. In this tan, or quas, as the workmen call it, the saffians lie eight days and nights, adding fresh tan every other day; so that four tans are necessary.

Here it must be observed, that some Armenians who prepare saffians, for enhancing the quality of the red colour of their saffians, to half a pound of cochineal add two lots, or rather more of sorrel, (or lutor, or loter, as they call it,) in the dye-kettle, but it is usually omitted in Astrachan, on account of its high price; for which reason the Astrachan saffians are excelled by the Turkish in beauty of colour. Secondly, it is to be known, that instead of the leaves of the tan-tree, bruised nut-galls are held to be still more serviceable for giving the saffians the tan. By this means, the colour is so durable as never to pass away but with the leather; whereas the saffians prepared with the tan-tree begin soon to be discoloured. But the nut-galls are likewise too dear in Astrachan to be customarily used by the saffian-makers. The Kazan Tartars colour their saffians with red wood, and tan them with the shrub *uva ursi*, but it makes the worst saffians of all, as they presently fade.

When the saffians are lifted out of the tan, still the last work remains. They are first left some time in the air to dry, they are afterwards scraped on the stretch-bank with sharp scrapers on the flesh side, quite smooth and clean, then washed in running water, each skin duly stretched with pegs all round the edges, and thus left till they are dry.

The skins must now be smoothed on the hair side with a wooden instrument for that purpose; and lastly, they are laid on a thick felt, where, with an iron heckle that has blunt points, those little pittings, which the saffians are generally seen to have, are impressed on the same side. And thus they are ready for sale, without being smeared with linseed-oil, as is mentioned in Gmelin's travels, which would infallibly spoil them.

The yellow saffians are little made in Astrachan, as the demand for them is much less, and there are but few saffian-makers who know much of the matter. The dye which they make use of for this purpose is of the berries of a sort of *ramnus* (perhaps *lycioides*), which are brought from Persia under the name of *ulofcharr*, and usually bought for six to nine rubles the pood. The Kazan Tartars colour their ordinary yellow saffians with the flowers of the yellow camomile, which they gather under the name *sare tshet-schiak*, i. e. yellow-flower.

In preparing the yellow saffians, they observe in Astrachan the following difference of treatment: 1. They make no use whatever of honey in the preparation. 2. They

never at all put the hides into the salt brine. 3. Instead of the honey-preparation and the pickling, they lay the hides before the dyeing, in the foregoing manner, in the tan of the leaves of the kitzhar tan-tree, leaving them in it eight days. 4. For preparing the dye, they have no need of the herb tschagan, but the berries alone are boiled in clear water, of which to four Russian vedros of water about ten pounds are requisite, and heighten the colour afterwards with three lots of alum to every pound of berries. The dyeing is

performed in the same manner as has been related with the red, and after the dyeing there is no need to lay the saffians in the tan, as having before received it. Nothing more is necessary than to scrape them clean, to work them thoroughly, to polish and to ornament them. The yellow saffians usually are sold at one ruble twenty kopeeks; but the red at somewhat more, on account of the dearness of the dye, generally one ruble eighty kopeeks.

Zinc

ZINC, in *Chemistry*, the name of a metal, in Latin *zincum*. The ancients do not appear to have been acquainted with this metal. *Cadmia* was the name by which they seem to have known one of its ores, which was so called from Cadmus, who, it is said, taught the Greeks how to form brass by its means. It is first mentioned by Albertus Magnus, but it is doubtful if he had ever seen it. The word *zinc* first occurs in the writings of Paracellus. This metal has been also called *spelter*.

Zinc has never been found in Europe in a state of purity, and chemists were late in discovering a method of extracting it from its ores. Henkel seems to have been one of the first who effected this about the year 1720, and he was soon followed by others. Zinc is of a brilliant white colour, with a shade of blue, and seems to be composed of a number of thin plates adhering together. It imparts a perceptible smell and colour to the skin when rubbed by it for some time; hence it is rather soft. Its specific gravity is said to vary from 6.86 to 7.1, the lightest being esteemed the purest. When hammered, its specific gravity becomes as high as 7.19.

This metal is by no means so malleable as copper, lead, or tin; it is not however brittle. It yields, and becomes somewhat flatter, when struck with a hammer. When heated a little above 212°, it has the remarkable property of becoming very malleable, and in this state may be reduced into very thin plates, either by hammering or rolling. When heated to about 400°, it becomes so brittle that it may be reduced to powder in a mortar.

Zinc may be drawn into wire. According to Muschenbroeck its tenacity is such, that a wire of $\frac{1}{4}$ th of an inch in diameter is capable of supporting a weight of about 26 lbs.

Zinc melts at a temperature of about 680°, according to Dr. Black. If the heat be increased it evaporates, and may be easily distilled over in close vessels: upon this property of zinc, Von Swab's method of extracting it from its ore was founded. When allowed to cool slowly, this metal crystallizes beautifully in small bundles of quadrangular prisms disposed in all directions, which, if exposed to the air while hot, assumes a blue changeable colour.

When exposed to the air, zinc soon tarnishes, but it scarcely undergoes any other change. When kept under water, its surface becomes black, the water is decomposed, hydrogen is emitted, and the oxygen combines with the metal. If heat be applied, these changes go on more rapidly; and if the steam of water be made to pass over zinc at a high temperature, it is very rapidly decomposed.

When this metal is kept melted in open vessels, it soon becomes covered with a grey pellicle of oxyd. If the heat be very strong it takes fire, and burns with a brilliant white flame, and at the same time emits a great quantity of very light white flakes. This is merely the oxyd of zinc. It was well known to the ancients, and received from them many whimsical names, such as *pompholyx*, &c. Among the alchemists it was known by the names of *nihil album*, *lana philosophica*, *flowers of zinc*, &c.

Zinc appears to combine with only one proportion of oxygen, which has been stated by different chemists to vary from 24.16 to 25 of oxygen to 100 of the metal. According to the first of these determinations, the weight of the atom of zinc will be 41.39; according to the second 40. Dr. Thomson has decided upon 41.25 as the most probable weight of the atom.

Zinc combines readily with chlorine, and forms a chloride of zinc. It may be prepared by dissolving zinc in muriatic acid, or by exposing the metal to the gas, when the two combine by a species of combustion. The chloride may be also obtained by distilling zinc-filings with the oxy-muriate of mercury, or *corrosive sublimate*; and thus obtained, it was formerly denominated the *butter of zinc*. When thus prepared, it sublimes on the application of heat, and crystallizes in needles; but according to Dr. Davy, when the common muriate is heated in a glass tube, it does not sublime even at a red heat, but remains in a state of fusion. Exposed to the air, it soon deliquesces. According to Dr. J. Davy's analysis, it is composed of

Chlorine	-	-	-	100
Zinc	-	-	-	100

But if we suppose it to be composed of an atom of zinc

and an atom of chlorine, and the atom of zinc to weigh as above, its constituents should be

Chlorine	-	-	-	100
Zinc	-	-	-	91.6

Zinc readily combines with iodine by heat. The compound, or *iodide*, is white. It is volatile, and crystallizes in fine quadrangular prisms. It deliquesces in the air, and is very soluble in water. The solution is colourless, and does not crystallize. Gay Lussac has shewn, that this compound consists of one atom iodine, and one atom zinc, or by weight of

Iodine	-	-	-	100
Zinc	-	-	-	26.52

No compound of zinc with fluorine is at present known. Zinc does not combine with azote nor hydrogen; nor are we acquainted with any compound of this metal with boron and silicon.

Zinc may be combined with phosphorus by dropping small bits of phosphorus into it while in a state of fusion. Phosphuret of zinc is of a white colour, and possesses a metallic lustre, which more resembles lead than zinc. It is somewhat malleable. It emits the odour of phosphorus when filed or hammered, and if exposed to a strong heat it burns like zinc. Phosphorus also appears to combine with the oxyd of zinc, and to form a peculiar compound.

Sulphur cannot be combined artificially with zinc; but if melted with the oxyd of zinc a peculiar compound is formed. A similar compound is formed when sulphuretted hydrogen in combination with an alkali is dropped into a solution of zinc. It is at first white, but becomes darker on drying. Dr. Thomson considers this compound as a sulphuret of zinc. Mr. E. Davy ascertained, that when the vapour of sulphur is passed over zinc in fusion a yellowish compound is obtained, similar in appearance to blende.

One of the most common ores of zinc is *blende*, described below, and which is a sulphuret of zinc, composed, according to Dr. Thomson's experiments, of

Zinc	-	-	-	100
Sulphur	-	-	-	48.84

Hence he considers it as a compound of one atom zinc, and one atom sulphur.

The alloys of zinc and the metals of the fixed alkalies are speedily decomposed by exposure to the air or immersion in water. We are not acquainted with the alloys of zinc and the metallic bases of the alkaline earths.

Zinc may be combined with arsenic by distilling a mixture of it and arsenious acid. With iron, zinc combines with difficulty; the alloy when formed, according to Lewis, is hard, somewhat malleable, and of a white colour, like silver. Malouin has shewn, that zinc may be used instead of tin for covering iron plates; a circumstance which demonstrates an affinity between the two metals.

Zinc does not appear capable of combining with nickel or cobalt by fusion. The alloys of zinc with manganese, cerium, and uranium, are unknown.

For the other alloys of zinc, see the different metals; particularly for the most important of them or brasse, see BRASS and COPPER.

Salts of Zinc.—Almost all the acids act with energy on zinc, in consequence of its powerful affinity for oxygen. The salts of zinc, therefore, are very easily formed, and on account of their being but one oxyd of zinc are not much liable to variation.

Nitrate of Zinc.—The nitric acid attacks zinc with such energy, that it is commonly necessary to moderate its action by diluting it with water. Even then much heat is evolved, and a strong effervescence is produced by the escape of nitrous oxyd gas. The solution is transparent and colourless, very caustic, and yields by evaporation flat, striated, tetrahedral prisms, terminated by four-sided pyramids. These crystals attract moisture on exposure to the air, and are soluble in water and alcohol. When heated they melt, and if thrown on burning coals, detonate with a red flame.

Carbonate of Zinc.—*Calamine*, one of the ores of zinc, is a native carbonate of zinc, as described below. This salt usually exists in the form of a white powder, and may be obtained by precipitating zinc from its solution in acids by an alkaline carbonate.

Phosphate of Zinc.—The phosphoric acid unites in two proportions with the oxyd of zinc. The neutral phosphate is a tasteless white powder insoluble in water. The bi-phosphate is soluble in water, if not exposed to too great a heat. It does not crystallize, and is strongly acid.

Sulphate of Zinc.—Concentrated sulphuric acid scarcely acts upon zinc without the assistance of heat; but when diluted it acts upon the metal very strongly, and hydrogen gas is given out in abundance. In this case, the water is decomposed, its oxygen combines with the metal, while its hydrogen escapes. The solution, when concentrated, yields crystals in abundance.

This salt, formerly known under the name of *white vitriol*, was discovered in Germany, about the middle of the 16th century. When quite pure, it is perfectly white. The form of its crystals is that of flat quadrangular prisms, terminated by four-sided pyramids. At a temperature of 60°, it dissolves in about 1.4 times its weight of water. In boiling water, it dissolves in any quantity whatever. The constituents of this salt are,

1 Atom of sulphuric acid	-	-	31.74
1 Atom of zinc	-	-	32.54
5 Atoms of water	-	-	35.72
			100.00

When heated, the crystals part with their water, and if the heat be strong, the whole of the acid likewise separates, and leaves the oxyd of zinc in a state of purity. See VITRIOL, *White*.

Muriate of Zinc.—See *Chloride of Zinc*, *supra*.

Sulphite of Zinc.—This salt exists in the form of crystals, soluble in water, but insoluble in alcohol. On exposure to the air, they are soon converted into the sulphate of zinc. Fourcroy and Vauquelin describe a *hypo-sulphite of zinc*, which assumes the form of four-sided prisms, terminated by four-sided pyramids. They are soluble in water and alcohol.

Borate of Zinc is a white insoluble powder. It may be formed by pouring borate of soda into the nitrate or muriate of zinc.

Arseniate of Zinc is a white insoluble powder, and may be formed by mixing solutions of the alkaline arseniates with the sulphate of zinc.

Acetate of Zinc.—This salt exists in the form of rhomboidal or hexagonal plates of a talky appearance, and is not very soluble in water. Solutions of this salt form an excellent external application to inflammations.

Oxalate of Zinc.—This salt is a white powder, little soluble

in water, and may be formed readily by double decomposition.

Tartrate and Citrate of Zinc.—Both these salts exist usually in the form of powders, and are but little soluble in water. They may be procured, like the oxalate, by double decomposition.

The other salts of zinc are of very little importance or interest, and do not therefore merit to be enumerated here. The salts of zinc may be distinguished in general by their forming colourless solutions in water, by their yielding white precipitates with prussiate of potash, sulphuretted hydrogen, and the alkalies, and by the characteristic circumstance that zinc is not precipitated in the metallic state by any other metal.

Uses of Zinc and its Compounds.—Neither this metal nor its compounds, if we except *brass*, are much employed in the arts nor in medicine. A chief use of zinc is in the formation of galvanic apparatus, and in electrical experiments. (See GALVANISM and ELECTRICITY.) As it is not a poisonous metal, it has been recommended instead of tin and lead for domestic purposes; but the ease with which it is oxydized makes it very unfit for all sorts of culinary apparatus.

The strong affinity of zinc for oxygen renders it of great use as a chemical agent for precipitating other metals from a state of solution in the metallic state. The oxyd of zinc is used in medicine, both internally as a tonic, and externally mixed with hog's-lard as an ointment. The native carbonate is also used in the same manner as an external application. See UNGUENTUM *Calamine*, and UNGUENTUM *Zinci*.

The *sulphate* and the *acetate* are the only salts of zinc used in medicine; for the properties of which, see above.

ZINC, Ores of, in Mineralogy. The ores of zinc are generally associated with lead-ores, and exist abundantly in various parts of England; particularly in veins in the mountain lime-stone of Derbyshire, Durham, Cumberland, Yorkshire, Somersetshire, and North Wales. The ores of zinc are either oxyds, carbonates, or sulphurets of zinc, and are principally known as *calamine* or *blende*. There is an ore of zinc hitherto found only in North America, called by Dr. Bruce red zinc-ore; it occurs in several of the iron-mines in Sussex county, New Jersey.

Red Zinc Ore is of a blood-red or aurora-red colour: it occurs massive and disseminated. The fresh fracture is shining, but becomes dull after long exposure to the air, and is covered with a pearly crust; the principal fracture presents a foliated structure; the cross fracture is conchoidal. It is opaque or translucent on the edges; it yields a brownish-yellow or orange streak; it is brittle. The specific gravity is 6.22. It is infusible without addition by the blow-pipe, but melts into a transparent yellow bead with borax. When pounded and mixed with potash, and exposed to heat, it melts into an emerald-green mass, which, on solution in water, yields the same colour; but on the addition of the mineral acids is immediately changed to rose-red. This ore is soluble in the mineral acids. Its constituent parts are,

Zinc	-	-	-	-	76
Oxygen	-	-	-	-	16
Oxyds of manganese and iron					8
					100

Bruce's American Mineralogical Journal, p. 69.

According to Dr. Bruce, this ore possesses advantages in the manufacture of brass over those generally used; for without any previous preparation, it affords with copper

brass of the very finest quality, possessing a high degree of malleability, and suited for the most delicate workmanship. Red zinc-ore is characterized and distinguished from red silver-ore and red lead-ore by its infusibility; the latter melting into a blackish slag before the blow-pipe. Red orpiment, with which it might be confounded, is distinguished from red zinc-ore by its volatility, and the garlic smell which it yields. This ore of zinc has greater specific gravity than red copper-ore, and its solution in acids is colourless; but those of red copper are green. *Calamine* is divided by some mineralogists into four kinds, sparry calamine, compact calamine, earthy calamine, and electric calamine.

Sparry Calamine: Zinc Carbonaté, Haüy.—Its colours are greyish and yellowish-white, and sometimes green and reddish-brown. It occurs massive, botryoidal, cellular, stalactitic, and crystallized, in acute and obtuse rhomboids, and in longish quadrilateral tables: the crystals are small. The lustre of sparry calamine is between resinous and vitreous. The structure is imperfectly lamellar, and sometimes radiated. It is translucent, or more or less transparent; it yields easily to the knife. The specific gravity is 4.3. It is infusible before the blow-pipe, and loses about 34 per cent. by ignition. With muriatic acid it effervesces, and is dissolved. According to Smithson, the constituent parts of this ore from Derbyshire are,

Oxyd of zinc	-	-	65.2
Carbonic acid	-	-	34.8
			100.

From Somersetshire,

Oxyd of zinc	-	-	64.8
Carbonic acid	-	-	35.2
			100.

Compact Calamine: Zinc Carbonaté, Haüy.—Its colours are, greyish, greenish, or yellowish, and often brown, from an intermixture with iron. It occurs massive, botryoidal, disseminated, stalactitical, reniform, and mamillated: it has a dull, feebly glistening, resinous lustre. The fracture is uneven and coarse-grained, or splintery, and sometimes even a flatty conchoidal. It sometimes occurs in concentric lamellar concretions: it is opaque. Its chemical characters and constituent parts are the same as of the sparry calamine, these minerals being only varieties differing in form from each other.

Earthy Calamine: Zinc Carbonaté, Haüy.—It is of a greyish or yellowish-white colour, sometimes snow-white; externally it is frequently covered with a tint of yellowish-brown. It occurs massive, and coating other minerals; it is opaque, and has an earthy fracture; it yields to the nail, and adheres to the tongue. The specific gravity is 3.358. According to Smithson, the constituent parts are,

Oxyd of zinc	-	-	71.4
Carbonic acid	-	-	13.5
Water	-	-	15.1
			100.

Electric Calamine: Zinc Oxydé, Haüy.—Its prevailing colours are, greyish, blueish, or yellowish-white; externally it is sometimes brownish or blackish. It occurs crystallized, mamillated, botryoidal, stalactitical, and massive. The crystals are six-sided prisms, with dehdral summits, or acute

octahedrons; sometimes truncated on the summits. The crystals are small, and either solitary, or radiating in groups, like zeolite. The lustre is shining, glistering, and vitreous: the structure is imperfectly lamellar, or divergingly fibrous. It is sometimes opaque, and sometimes translucent or transparent: it yields to the knife, but is much harder than common calamine. The specific gravity is 3.4. When gently heated it is strongly electric; it is infusible, and loses about 12 per cent. by ignition. It is soluble in muriatic acid with effervescence: the solution gelatinizes on cooling. According to Klaproth, its constituent parts are,

Oxyd of zinc	-	-	-	66
Silex	-	-	-	33
				99
				—

According to Smithson,

Oxyd of zinc	-	-	-	68.3
Silex	-	-	-	25.
Water	-	-	-	4.4
				97.7
				—

Calamine sometimes occurs in what are called supposititious crystals, as if it had been moulded over crystals of other minerals, and the internal crystal had disappeared. In Derbyshire, the working miners are of opinion, that the calamine destroys the lead-ores when they occur together; or, as they express it, the calamine eats up the lead. That some process of decomposition or change takes place where these ores are associated there can be no doubt; but by what means this is effected we are at present ignorant. See *VEINS, Metallic*.

Calamine, commonly called lapis calaminaris, when cleaned and roasted, is used for the fabrication of brass, forming a compound with copper. (See *BRASS*.) Its uses in the making of brass is of very high antiquity, being mentioned by Aristotle.

Calamine is also the most valuable ore from which metallic zinc is extracted.

The uses of calamine were not known in England before the reign of queen Elizabeth, and even so late as the year 1700 it was commonly carried out of the kingdom as ballast by the ships which traded to Holland. The calamine raised in Derbyshire about the year 1780 amounted to 1500 tons. Sixty years before that time the quantity got did not exceed 40 tons, the greater part being thrown away through ignorance of its nature and value.

The dressing of calamine consists principally in picking out all the pieces of lead-ore, lime-stone, iron-stone, heavy spar, and other minerals mixed with it in the mine. The picked calamine is then calcined in proper furnaces, and loses by calcination between a third and fourth part of its weight, which is the carbonic acid. In great works, where calamine is prepared for the brass-makers, after its calcination, it is carefully picked again, the accidental ingredients being rendered more discernible by the action of fire. It is afterwards ground to a fine powder, and washed in a gentle rill of water, to free it from earthy particles with which it may be intermixed; for these being lighter are carried off by the water: it is then made up for sale.

A ton of the crude Derbyshire calamine, as dug from the mine, is reduced, by the various processes it undergoes before it becomes fit for use, to about twelve hundred weight. Part of the zinc is lost in calcination, particularly if too strong a fire be made: this is evident by the flame visible over the furnace. It would be practicable to use calamine without calcining it, for the carbonic acid would be expelled

by the heat applied in making brass; but then there would be seven or eight hundred weight put into the brass pots which would be of no use in the operation: it is therefore better to get rid of so large a quantity of unserviceable matter, and thereby avoid also an increased expence of carriage from the calamine-furnace to the places where the brass is made. Watson's Chemical Essays, vol. iv.

Blende comprises various sulphurets of zinc, differing in the proportion of their constituent parts, and the admixture of other mineral substances.

Yellow Blende, or Phosphorescent Blende: Zinc Sulphur Jaune, Brongniart.—The prevailing colours of this ore are yellow, passing into green, and sometimes hyacinth-red, aurora-red, or brownish-red. It occurs massive, disseminated, and crystallized. The crystals are generally small, middle-sized, and so closely aggregated, that it is difficult to determine the precise figure, which appears either the rhomboidal, the dodecahedron, the octahedron, or the tetrahedron. Yellow blende is translucent, passing into transparent, and has a splendid adamantine lustre. It yields to the knife, and affords a yellowish-grey or yellowish-white streak: it is brittle. The specific gravity rather exceeds 4: according to Karlfon, it is 4.1.

It decrepitates before the blow-pipe, and becomes grey; but is infusible either alone or with borax. By friction it becomes phosphorescent, and, according to Bergman, acts as powerful in this respect in water as in air.

Foliated Brown Blende: Zinc Sulphur Brun, Brongniart.—It is of a reddish or yellowish-brown, passing into blackish-brown and dark red. It occurs massive, disseminated, and crystallized. The form of the crystals is a rhomboidal dodecahedron, either perfect or truncated on the alternate lateral angles and edges, or an octahedron, either perfect or truncated. It occurs also in tetrahedrons, perfect or truncated, and in rectangular four-sided prisms, six-sided prisms, and acicular crystals. Sometimes the crystals are joined, forming a twin crystal. The lustre is shining or splendid, and either resinous, adamantine, or semi-metallic; it has a straight lamellar structure, with a cleavage in six directions. It is more or less translucent; it yields to the knife, and affords a yellowish-grey or yellowish-brown streak; it is brittle, and easily frangible. The specific gravity of this ore varies from 3.7 to 4. It is infusible, and yields an hepatic odour when digested in sulphuric acids. The constituent parts of blende are given as under; but some varieties of foreign blende contain silex, arsenic, and manganese, which may be regarded as accidental.

Blende from Sattberg, according to Bergman:

Zinc	-	-	-	44
Iron	-	-	-	5
Sulphur	-	-	-	17
Silex	-	-	-	24
Alumino	-	-	-	5
Water	-	-	-	5
				100
				—

From Allonhead, in Northumberland, according to Dr. Thomson:

Zinc	-	-	-	58.8
Iron	-	-	-	8.4
Sulphur	-	-	-	23.5
Silex	-	-	-	7.
				97.7
				—

Fibrous Blende.—The colour is reddish-brown: it occurs reniform and massive. The structure is divergently fibrous in one direction, and concentric lamellar in the other: its lustre is resinous; it is opaque or faintly translucent at the edges; it agrees in other characters with foliated blende. The constituent parts are given as under in the Journal des Mines, t. xlix. No. 13.

Zinc	-	-	-	-	62
Iron	-	-	-	-	3
Lead	-	-	-	-	5
Arsenic	-	-	-	-	1
Sulphur	-	-	-	-	21
Alumine	-	-	-	-	2
Water	-	-	-	-	4
					—
					98
					—

Black Blende: Zinc Sulphuré Noir, Häüy.—It is of a greyish or velvet-black colour, and sometimes brownish-black. When translucent, it appears blood-red; it is sometimes tarnished with various colours. It occurs massive, disseminated, and crystallized, in the same forms as brown blende; internally it is shining, sometimes splendent; and the lustre is adamantine, inclining to metallic. It has a foliated structure, and six-fold cleavage. The fragments are angular, and rather sharp-edged. It is almost always opaque. The streak is intermediate, between yellowish-grey and lightish-brown: it is easily frangible. The specific gravity varies with the admixture of ingredients in this ore, from 3.9 to 4.1. Auriferous blende from Nagyag, as given by Muller, is 5.39.

The constituent parts of black blende are as under:

Zinc	-	45	53
Iron	-	9	12
Lead	-	6	0
Arsenic	-	1	5
Sulphur	-	29	26
Silex	-	4	0
Water	-	0	4
		—	—
		100	100
		—	—

Blende is distinguished from tin-stone by its inferior hardness; it yields pretty easily to the knife. It may be distinguished from other ores which resemble it, by the sulphureous odour which it yields when thrown into an acid, or triturated in a mortar. The common name given to this ore by the English miners is Black Jack. It frequently occurs in the upper part of the metallic veins in Cornwall, that are rich in other ores below. Blende is not so valuable an ore of zinc as calamine: it must be freed from its sulphur by calcination before it can be applied to the making of brass. Some blendes lose one-fourth of their weight, others one-sixth by calcination. It has been for many years used for making brass at Bristol as well as calamine; but so little was this application of it known in other parts of the kingdom, that in the year 1777 we are informed by Dr. Watson, in his Chemical Essays, that its use in Derbyshire was but recently discovered; and he was requested not to divulge the purpose to which it might be applied, probably to evade the dues on minerals payable to the duchy court of Lancaster.

Addenda and Corrigenda

TIN, CRYSTALLIZED, a kind of manufacture said to have been accidentally discovered in France by M. Baget, called metallic watering, or *moiré metallique*. It depends upon the action of acids, either pure or mixed together, and in different degrees of dilution, on alloys of tin. The variety of designs resembles mother-of-pearl, and reflects the light in the form of clouds. The process is this:—First, dissolve four ounces of muriate of soda in eight ounces of water, and add two ounces of nitric acid.—Second mixture; eight ounces of water, two ounces of nitric acid, and three ounces of muriatic acid.—Third mixture; eight ounces of water, two ounces of muriatic acid, and one ounce of sulphuric acid. One of these mixtures is to be poured warm upon a sheet of tinned iron, placed upon a vessel of stone-ware: it is to be poured on in separate portions, until the sheet is completely watered; it is then to be plunged into water, slightly acidulated, and washed. The watering obtained by the action of these different mixtures upon tinned iron, imitates very closely mother-of-pearl and its reflections; but the designs, although varied, are quite accidental. By heating the tinned iron to different degrees of heat, stars, fern-leaves, and other figures, are produced; and by pouring one of the above mixtures, cold, upon a plate of tinned iron, at a red heat, a beautiful granular appearance is obtained. These metallic waterings will bear the blow of a mallet, but not of a hammer; hence the invention may be used for embossed patterns, but not for those which are punched. Different colours and shades may be given by varnishes, which, when properly polished, will set off the beauty of the watering. When the tin is upon copper, the crystallization appears in the form of radiations or stars. M. Lewis Felix Vallet obtained a patent for an invention of this kind, upon delivering the following specification, Feb. 5th, 1818. The process of giving the new ornamental surface on metals or metallic compositions, consists in employing those acids and saline compounds and substances which chemically act upon tin, and which, when employed in the manner to be stated presently, give to the metals or metallic compositions to which they are applied the appearance of a crys-

talline surface variously modified. To produce this effect, the metal or metallic composition ought to be previously tinned, or covered with a thin coat of tin. If the metal be pure tin, it requires no previous preparation. All grease remaining on the tinned surface in consequence of tinning is to be taken off with a solution of potash, soap, or any other alkaline substances. The tin or tinned surfaces should then be washed with pure water, dried and heated to a temperature which the hand can bear. When the surface has thus been cleaned and heated, any of the acids which act upon tin, or the vapours of those acids will cause the desired appearance of crystallization; but I give the preference to the following composition, which may conveniently be laid over with a brush or a sponge. Take one part by measure of sulphuric acid, dilute it with five parts of water; take also one part of nitric acid, and dilute it with an equal bulk of water, and keep each of the mixtures separate. Then take ten parts of the sulphuric acid diluted in the manner before stated, and mix it with one part of the diluted nitric acid, and then apply this mixed acid to the tin, or to the tinned surface with a pencil or sponge, as above directed, and repeat the application of the said composition for several times successively, or until the result you expect proves satisfactory. When this has been done, the crystalline surface may be covered with a varnish or japan more or less transparent or colourless, or coloured, and lastly polished in the usual manner. Mr. Shaw, of Brunswick-square, purchased this patent, and tin-plates were made under its protection, at the manufactory of Mr. Burnell, at Battersea. But the process being generally known among chemists, the manufacture declined, and the patent, for which a considerable sum was paid, became of little value.

TIN-Plates. Add—The manufactory for tinning iron-plates was established at Pontypool by major John Hanbury, where he resided until his death in 1734; and the invention of the art has by some persons been erroneously ascribed to him. His monument may be seen in Trevellin church.

VOLTAISM, l. 13.—The general conclusion deduced by Galvani from his experiments was, that the animal body possesses an inherent electricity of a specific kind, which is connected with the nervous system, and conveyed by means of the metals into the muscles, so as to throw them into convulsions. From his discoveries he formed, with a precipitance that led him into error, a theory of muscular motion, according to which the body contains an apparatus analogous to the Leyden phial, its different parts being in different states of electricity, and the metals forming a connection between them, by which the electricity is equalized. Fowler, in his "Essay on Animal Electricity," published in 1793, concludes, that the galvanic influence is not referable to electricity, because, for the production of the former, the presence of two different metals appears to be necessary, while electricity, as proceeding from the electrical machine, is excited by the action of an electric upon a conductor. He also endeavours to shew, says Dr. Bostock, the ingenious historian of galvanism, that electricity and galvanism are not, in all cases, conducted by the same substances; and he also made some curious observations upon the effect of galvanism on animals not furnished with distinct limbs, such as worms of various kinds. In the same year, 1793, professor Volta's communications appeared in the Philosophical Transactions of London, who adds to his luminous account of Galvani's discovery many curious experiments and observations of his own. He attempted, and with complete success, says Dr. Bostock, to overthrow Galvani's opinion, that the animal body bears an analogy to the Leyden phial, its different parts being in opposite states of electricity. He suggested, that for the production of the effect it was essential to have two different metals; and hence he was led to conclude, that the muscular contractions are produced by small portions of electricity that are liberated by the action of the metals upon each other. This action of the metals upon each other is described as destroying their electrical equilibrium; and by establishing a communication between them, their equilibrium is restored. This destruction of equilibrium he considers as a new law of electricity discovered by himself; and the animal is supposed to have no further concern in it, than as being a peculiarly sensible electrometer, and affording a very delicate test of the presence of this disengaged electricity in its passage from one metal to the other. He also established

another point, *viz.* that the nerve is the organ on which the galvanic influence immediately acts; but he found that if a part of a muscle be laid upon two different metals, and these be made to communicate, a contraction is produced. He also confirmed the fact, previously noticed by Fowler, but by independent experiments, that snails and worms could not be made to contract; but that many of the insects, as butterflies and beetles, were subject to the influence of the metals. For an account of Dr. Wells's experiments and observations, we refer to his paper in the Phil. Transf. for 1795. Professor Volta, prosecuting his inquiry into the nature of galvanism, was led to introduce a new principle into his theory. Having before stated that two metals were essential to the extrication of the electric influence, he informs us, that their metallic nature may be dispensed with, provided that the substances differ in their power of conducting electricity. Accordingly he divides conductors into the two classes of dry and moist; the first including metals and charcoal; the latter, essentially consisting of water, holding various substances in solution. In order to form a galvanic circuit, it is necessary that a body from one of these classes be placed between two bodies from the other class: and thus the equilibrium is destroyed, which is again restored when the two are united by a conductor. (See GALVANISM.) For further particulars we are under a necessity of referring to Dr. Bostock's very valuable "Account of the History and present state of galvanism," 8vo. London, 1819.

At the close, add—It is natural to conclude, that galvanic electricity would be applicable to medical purposes. Accordingly we find, that about the year 1804, it was extensively employed, more especially in those diseases in which common electricity had been found useful. But the expectations that were formed concerning the efficacy of this powerful agent were generally disappointed. Flattering accounts, however, says Dr. Bostock, (*ubi supra*) of its success in different nervous disorders, in paralytic affections, in deafness, in some kinds of blindness, in the recovery of persons apparently drowned or suffocated, and even in hydrophobia and insanity, were published. But the credit of the proposed remedy was not permanent; and it therefore sunk into disuse. Of late it has again been brought into notice by Dr. Philip of Worcester, who has made trial of it, with beneficial effect, in spasmodic asthma. Bostock's Hist.